

AMELIORATION OF SALINITY STRESS IN RICE CULTIVATION OF WEST BENGAL

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ABSTRACT

West Bengal a prominent rice-producing state in India, faces significant challenges related to soil salinity, particularly in its coastal regions and the Sundarbans delta. Salinity adversely impacts rice productivity by affecting soil structure, nutrient availability, and water uptake by plants. This is a critical issue in saline- prone district like south 24 parganas, North 24 paraganas, and Purba Medinipur, where tidal intrusion and rising sea level exacerbate the problem. Research highlights that salinity stress reduces germination rates, plants growth, and grain yield in rice, a staple food crop for millions in the state. This issue has included introducing salt- tolerance rice varieties such as Swarna sub1, Nona Bokra, and CSR 43, along with improved agronomic practices like proper drainage system. The study undergoes the importance of adaptive strategies to mitigate salinity effects, including sustainable water management, genetic enhancement of rice varieties, and community engagement. These measures the essential to ensure food security and the economic stability of farmers in the salinity – affected regions of west Bengal. Further research and policy investigations are required to address the long-term impacts of salinity of rice cultivation in the state.

Keywords: *Rice variety, Rice cultivation, Sustainable water management, Salinity stress, West Bengal.*

INTRODUCTION

Rice is the major food for the millions of people. Rice is also the main food crop for the people in coastal flood-prone areas of southeast Asia. In India, these areas are distributed over nine states (Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Odisha, Tamil Nadu, and West Bengal) and four union territories (Andaman and Nicobar, Lakshadweep, Daman and Diu, and Puducherry) but the state of WB has the highest area under the coastal saline lands (0.82 million hectares) and as a consequence of climate change, rice production in recent years is highly variable due to the increase of flood or drought, besides widespread occurrence of saline soil with variable saline levels. High monsoon rainfall, poor soil and water quality and natural weather adversities like coastal storms and cyclones make agriculture in these areas more complex and risky.

Rice exhibits enormous genetic variability in their salt sensitivity. The indica varieties Pokkali and Nonabokra (NB) are classified as highly salt-tolerant ecotypes, while the high yielding varieties like M-1-48, IR-29, IR-72, IR-36 and Taichung Native-1 are salt-sensitive (Roychoudhury et al., 2008b). Alternatively, the aromatic indica rice varieties, which are highly demanding in the global market, because of their pronounced fragrance and elegant flavour, suffer huge crop losses due to their susceptibility to biotic and abiotic stress conditions. Our earlier observations (Roychoudhury et al., 2008a, Roychoudhury et al., 2009a, Roychoudhury et al., 2009b) showed that the aromatic rice Gobindobhog (GB) behaves as highly salt-susceptible variety suffering formidable oxidative damages with lower expression of stress-inducible genes in response to salinity and abscisic acid (ABA)-mediated stress injuries, meaning that the improvement of stress tolerance in this variety is a matter of serious concern. We focused on the exogenous application of PAs, Spd and Spm, as a means to study their protective potentiality in salt tolerance of M-1-48 (salt-sensitive), NB (salt-tolerant) and

particularly GB (highly sensitive) rice varieties. The root and shoot lengths, chlorophyll and endogenous ion content, lipid peroxidation (LP), protein carbonylation and protease activity in the three varieties, subjected to NaCl solution, either in presence or absence of Spd/Spm were analyzed. The defence response mechanism, in the form of some enzymatic and non-enzymatic antioxidant assay or compatible solute measurements were performed in the leaves of the three NaCl-treated varieties and their differential modifications in relation to exogenous Spd or Spm has been studied extensively and documented in this communication. Polyamines (PAs), including the diamine putrescine (Put2+), triamine spermidine (Spd3+) and tetramine spermine (Spm4+), are ubiquitous, low-molecular-weight, straight chain, aliphatic amines, ranging in concentration from 10 μ M to mM and involved in various biochemical and physiological processes related to the regulation of plant growth and development. Because of their polycationic nature at physiological pH, PAs are able to interact with proteins, nucleic acids, membrane phospholipids and cell wall constituents, thereby stabilizing these molecules. In recent years, much attention has been devoted to the involvement of PAs as second messengers in response to different environmental stresses (Alcazar et al., 2006, Liu et al., 2007) like osmotic stress, salinity, drought, heat, chilling, high light intensity, mineral nutrient deficiency, heavy metals, pH variation, UV-irradiation and exposure to pollution stress.

Salinity Stress

Saline soils are defined as having an electrical conductivity (EC) of 4 dS/m in a saturated soil-paste extract (Richard, 1954). However, Bresler et al. (1982) considered soil to be affected by salt when EC reaches 2 dS/m, as many fruit, vegetable, and ornamental plants experience salt toxicity between 2–4 dS/m. A soil is considered salinized if salt levels exceed certain limits: (1) 3–5 g/L of salt in the soil solution (Vargas et al., 2018), (2) 0.05–0.15% toxic salts in water extracts (Vargas et al., 2018), or (3) an EC of 2–4 dS/m in saturated soil-paste extracts (Bresler et al., 1982). In Eurasian countries, soil salinity is often measured using a soil/water extract ratio of 1:5 (Vargas et

al., 2018). However, preparing soil pastes and their extracts is time-consuming, so it is common to assess salinity using soil/water suspensions at ratios of 1:2.5, 1:5, or 1:10 and then adjust results using empirical formulas (Jahn et al., 2006). The equation $ECSE = 250 \times EC(2.5) / WCSE$ helps convert EC from a 1:2.5 suspension to a saturated paste extract, where ECSE is the EC of the saturated paste extract, EC(2.5) is the EC of the 1:2.5 suspension, and WCSE is the moisture content of the soil paste.

Soil salinity reduces crop production and threatens food security. In dry regions, salinity has caused yield losses of 18% to 43% (Vargas et al., 2018), worsening land degradation and climate change impacts, which can negatively affect local communities.

Hormone Regulation of Salinity Tolerance

ABA is an important plant hormone that helps plants cope with stress. When there is a shortage of water in the soil, ABA levels increase in the roots and shoots. Salinity stress, which happens when there is too much salt, also raises ABA levels. This hormone helps reduce the negative effects of salt on photosynthesis, plant growth, and the movement of nutrients. ABA helps plants tolerate salt by increasing the levels of important nutrients like potassium (K⁺), calcium (Ca²⁺), and protective substances like proline and sugars in the roots, which reduce the harmful effects of sodium (Na⁺) and chloride (Cl⁻). ABA also controls the activity of certain genes that help plants survive in salty and dry conditions. Studies by Fukuda and Tanaka showed that ABA affects genes responsible for important cell functions in barley (*Hordeum vulgare*) under salt stress. In wheat, ABA increased the activity of specific genes (MAPK4-like, TIP 1, and GLP 1) that help plants deal with salinity.

Some compounds with hormone-like effects, such as salicylic acid (SA) and brassinosteroids (BR), help plants cope with stress caused by harsh environmental conditions. When rice seedlings face salty conditions, their levels of SA increase, along with the activity of enzymes that produce SA. Research has shown that SA improves salt tolerance in

Arabidopsis by stabilizing cell membranes and preventing the loss of potassium (K^+) through a specific channel (GORK). Arabidopsis seedlings treated with SA had higher H^+ -ATPase activity, which helped them retain K^+ during salt stress.

While SA did not stop sodium (Na^+) from accumulating in the roots, it reduced Na^+ levels in the shoots. In barley, SA improved salt tolerance by increasing chlorophyll and carotenoid content, maintaining membrane stability, and promoting K^+ and sugar accumulation in the roots under salty conditions. Studies by Nazar et al. suggest that SA helps plants like mung beans withstand salt stress by boosting photosynthesis, nitrogen and sulfur absorption, and antioxidant activity.

Similarly, BRs help reduce salt stress by increasing the activity of antioxidant enzymes (SOD, POX, APX, and GPX) and raising the levels of antioxidants like tocopherol, ascorbate, and glutathione. Both SA and BRs are found in many plants and play important roles in growth and stress tolerance. Researchers have studied how applying SA and BRs externally can help plants withstand salt stress by improving biochemical and physiological processes.

The physiological and biochemical alterations under salinity stress

Effect on germination and seedling stage

Seed germination is a step-by-step process influenced by internal and external factors. Salinity stress can slow down germination by reducing water absorption and decreasing the activity of α -amylase, an enzyme that breaks down starch into sugars. High salt levels in the soil make it harder for seeds to absorb water, delaying germination and reducing the overall germination rate. Even after germination, excess salt can harm the embryo by accumulating toxic Na^+ and Cl^- ions. Salt stress also increases harmful reactive oxygen species (ROS), which damage important molecules in the seed. As a result, lower α -amylase activity reduces the sugar supply needed for embryo growth.

Under normal conditions, seed germination happens in three phases. In Phase I, dry seeds quickly absorb water (imbibition). In Phase II, metabolic activities resume, but water uptake slows down. Phase III is the post-germination stage, where water absorption continues until full germination. In salty conditions, Phase I faces osmotic stress, and Phase II experiences ionic stress, both of which delay germination. Even after sprouting, seedling growth in Phase III is affected by salt stress.

Salinity reduces seed germination by lowering gibberellic acid levels, increasing abscisic acid, altering membrane permeability, and reducing water absorption. Germination depends on enzymes like α -amylase, which break down starch into sugars that provide energy for the growing embryo and radicle. While seeds may still germinate under moderate salinity, the process takes longer. Delayed germination is mainly caused by slow water absorption and reduced α -amylase activity due to high salt levels. Salt-sensitive seeds experience a greater drop in α -amylase activity than salt-tolerant ones, which limits sugar movement and affects embryo development.

Ionic imbalance and salinity mediated nutritional deficiencies

Some ions, like K^+ and SO_4^{2-} , are important nutrients for plants, but Na^+ is not essential. That's why soil salinity is often measured by the levels of Na^+ and Cl^- . Salinity affects plants in three main ways. First, salt lowers the soil's water potential, making it harder for plants to absorb water, causing stress that slows growth and reduces yield. Second, when plants take in too much Na^+ and Cl^- , these ions become toxic, leading to leaf damage, stunted growth, and even plant death. Third, high Na^+ levels compete with other essential nutrients like K^+ , Ca^{2+} , and Mg^{2+} , leading to nutrient deficiencies. When salt levels rise, plants absorb more Na^+ than K^+ , which disturbs the balance of ions, disrupts nutrient uptake, and damages cell membranes. Research on rice has shown that salinity stress reduces nutrient levels (Fe, K, Mn, Mg, P, and Zn) in roots and shoots. It also decreases root surface area by reducing root hair density and length, which lowers nutrient

absorption. Essential elements like Ca^{2+} , Mg^{2+} , Fe^{2+} , and Zn^{2+} needed for

Oxidative stress caused by salinity

Salt stress harms plants in many ways, including causing an excessive build-up of reactive oxygen species (ROS). These harmful molecules can damage important cell components like DNA, proteins, and lipids, leading to enzyme inactivation, hormonal imbalances, and nutrient deficiencies. ROS are mainly produced in the chloroplasts, mitochondria, endoplasmic reticulum, cytosol, and peroxisomes.

Salt stress also causes stomatal closure, reducing the amount of carbon dioxide in leaves, which slows down photosynthesis. The light reactions in chloroplasts are a major source of ROS, including superoxide ($\text{O}_2^{\bullet-}$), hydrogen peroxide (H_2O_2), hydroxyl radical ($\text{OH}^\bullet$), and singlet oxygen ($^1\text{O}_2$).

Salt stress, combined with water shortage, disrupts plant metabolism and increases ROS production, causing further damage. Studies on crops like rice (*Oryza sativa*), maize (*Zea mays*), mung bean (*Vigna radiata*), and tomato (*Solanum lycopersicum*) have shown that salt stress lowers the ascorbate (ASA) to dehydroascorbate (DHA) ratio and reduces the activity of protective enzymes like superoxide dismutase (SOD) and catalase (CAT). It also increases methylglyoxal (MG), leading to oxidative damage. In rice seedlings, salt stress raised hydrogen peroxide (H_2O_2) and malondialdehyde (MDA) levels, while lipoxygenase (LOX) and SOD activity increased, but CAT activity decreased.

Effect on yield and yield components

Salinity stress reduces crop yields by affecting plant growth and key processes during the reproductive stage. The high-affinity K^+ transporter (HKT) family helps remove excess sodium (Na^+) from leaf blades, maintaining balance under salt stress. Studies show that grain dry matter and the K^+/Na^+ ratio are closely linked to grain filling rate and duration. Salinity also disrupts water movement, transpiration, nutrient balance, and stomatal function, leading to oxidative damage and lower yields. It affects leaf thickness, cell size,

and turgidity, reducing the plant's ability to produce food. Many crops, including moong bean, cabbage, tomato, and broccoli, experience lower yields due to salt stress.

Salt Stress Mitigation in Rice by Microorganisms

Some microorganisms can help plants grow better in salty conditions by reducing the harmful effects of salt stress. Recently, studies have found that using salt-tolerant microorganisms like *Pseudomonas multiresinivorans*, *Microbacterium esteraromaticum*, and *Bacillus subtilis*, along with organic fertilizers like farmyard manure, can help rice plants cope with salt stress and grow better.

Arbuscular mycorrhizal (AM) fungi also play an important role in helping plants deal with salt stress. These fungi improve plant growth by changing root structure and expanding the network of tiny filaments (hyphae) that absorb nutrients. AM fungi help plants tolerate salt by improving nutrient absorption, protecting enzyme activity, boosting photosynthesis, and making it easier for plants to take in water. They also help balance ions in the plant, reducing harmful sodium (Na^+) levels while increasing potassium (K^+) absorption. This balance prevents damage to important plant processes like enzyme function and protein production, helping the plant stay healthy even in salty conditions.

Salt Stress Mitigation in Rice by Plant Nutrients

Plants use different minerals like nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), and silicon (Si) to cope with environmental challenges. When crops face salt stress, their growth is affected because salt disrupts the movement and balance of nutrients. High levels of sodium (Na^+) and chloride (Cl^-) can interfere with essential nutrients like potassium (K^+) and calcium (Ca^{2+}), causing an imbalance. This stress harms plant growth due to toxic ions and nutrient deficiencies. Many fertilizers have high salt content, so they should not be applied too close to young plants. Adding gypsum can help protect soil structure, improve water absorption, and reduce sodium buildup. The next sections will discuss how minerals like calcium, manganese, and silicon help plants tolerate salt stress.

Salt Stress Mitigation in Rice by Phytohormones Application

It is identified that the phytohormones such as ethylene, gibberellins, abscisic acid, cytokinins, auxins, and brassinosteroids all regulate plant growth and development traits. The Abscisic acid (ABA) typically guards plants against different environmental stress conditions, analysed ABA's positive role in reducing the Cl^- and Na^+ concentrations and reducing transpiration in order to maintain water via switching the stomata of the plant. In addition, in rice plants, Na^+ , Cl^- , and K^+ were decreased due to exogenous application of ABA. Some other studies reported the role of exogenous use of ABA in increasing the rice salt stress tolerance. However, exogenous application of 100 μM of ABA in rice increased grain yield through more efficient accumulations of soluble sugar and proline as well as maintaining K^+ and Ca^{2+} equilibrium.

Alteration of salt-responsive genes, transcription factors, and protein synthesis

Plants regulate gene expression at different levels—before, during, and after making proteins—to respond to stress like salt. Studies on rice show that many genes change their activity under salt stress. Certain transcription factors, zinc finger proteins, and RNA processing enzymes play a role in this response. For example, proteins involved in RNA splicing, like tRNA splicing protein and AAR2, increase under salt stress. RNA-binding proteins (RBPs) also change their expression, suggesting they help regulate gene activity after transcription. Additionally, some translation initiation factors (eIFs) decrease in rice roots under salt stress, which may slow down protein production. Other proteins, such as poly A binding proteins (PABPs) and a nascent polypeptide-associated complex (NAC), also decrease, while some ribosomal proteins increase. This suggests that salt stress affects the process of making new proteins in rice, with different genes being activated or suppressed.

Proper folding and processing of proteins

Proteins can lose their shape and clump together under stress, which can make them stop working properly. To prevent

this, plants use heat-shock proteins (HSPs) and molecular chaperones (MCs) to help proteins fold correctly and stay functional. These proteins also help fix damaged proteins and keep cells healthy during stress. Studies show that proper protein folding is important for root function under salt stress. For example, a protein called rHsp90 is activated in rice roots under salt stress, and 23 other MCs (including HSPs and TCP1) increase in response to salt. Some MCs respond differently in genetically modified rice. The quick activation of HSPs and MCs helps keep proteins stable, which improves rice plants' ability to handle salt stress.

Conclusion and future prospective

Rice has been an important food for humans since ancient times. Changes in the environment can create stress conditions that harm rice crops, leading to major economic losses. Many fruits, vegetables, and ornamental plants face salt stress at electrical conductivity (EC) levels of 2–4 dS/m. In agriculture, salt stress limits crop growth and affects food security. Rice is especially sensitive to salinity, though it can tolerate some salt during germination, tillering, and maturity. However, high salt levels are harmful at the early seedling and reproductive stages. Salt stress affects rice growth by causing physiological and biochemical changes, reducing dry matter and grain yield. Researchers are working on ways to help plants survive stressful environments. Some promising methods to improve rice tolerance to salt stress include seed priming, beneficial microorganisms, applying nutrients like calcium, manganese, and silicon, using organic compounds like trehalose, and plant hormones such as abscisic acid.

Using biological approaches to improve rice under salt stress looks promising. It is important to identify key plant traits that help manage stress and find ways to enhance overall plant growth in salty conditions to maintain or increase rice production. Future research should focus on genetic, metabolic, and physiological changes in salt-stressed plants and how agricultural techniques—like priming, microorganisms, nutrients, organic compounds, and plant hormones—can help. Further studies in these areas will improve rice farming under salt stress in the near future.

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