Research Article

Germination and Growth Parameters of Rice *(Oryza sativa L.)* Germplasms under Salt Stress Conditions

Rashiduzzaman Emran[1,2], Abdul Hakim[2], Farhana Afroz Joty[2], Pinki Akter[3], Md. Mim Obaidullah[3], M. Ataur Rahman[2] and Md. Rayhan Chowdhury[2*]

[1]Department of Agricultural Extension, Khamarbari, Farmgate, Dhaka, 1215, Bangladesh; [2]Molecular Genetics Lab, Department of Genetic Engineering and Biotechnology, University of Rajshahi, Rajshahi-6205, Bangladesh; [3]Department of Biochemistry and Molecular Biology, Bangladesh University of Health Sciences, Bangladesh.

Rashiduzzaman Emran and Abdul Hakim are contributed equally to this work and considered as first author.

Abstract | Over fifty percent of the global population depends on rice (*Oryza sativa L.*) as a primary food source. Rice is grown on 161 million hectares worldwide, yielding an annual production of 678.7 million tons. Salinity is a significant abiotic determinant due to its extensive impact and prevalence. This study evaluated rice varieties for their tolerance to salt stress during germination and the early seedling growth stage. Seeds from three rice varieties (Shova, BRRI Dhan-56, and BRRI Dhan-57) were collected alongside a salt control variety, BRRI Dhan-61, and subjected to three levels of salt stress (NaCl). Statistical analyses were conducted on seed germination, seedling length, shoot dry weight, root dry weight, relative water content (both shoot and root), fresh weight percentage reduction, dry weight percentage reduction, salt tolerance index, and additional parameters. The findings indicated that increasing salt stress significantly reduced germination, shoot and root length, and biomass across all varieties. Increased salinity stress resulted in a decline in the dry weight of shoots and roots, as well as the lengths of shoots and roots, and the fresh weights of stems and roots across all rice varieties. The highest germination percentage, recorded at 93.33 % under 50 mM salinity stress and 69.87 % under 150 mM salinity stress, was observed in BRRI Dhan-56. The research findings may aid in diagnosing resistant plant varieties that warrant further investigation and treatment.

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***Correspondence** | Md. Rayhan Chowdhury, Molecular Genetics Lab, Department of Genetic Engineering and Biotechnology, University of Rajshahi, Rajshahi-6205, Bangladesh; **Email:** gebrayhan4@gmail.com
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Introduction

Rice (*Oryza sativa* L.) is a crucial staple food crop globally, sustaining about fifty percent of the world's population. Its productivity is significantly hindered by different abiotic challenges, with salinity being a principal environmental issue that restricts growth and yield, especially in coastal and irrigated agricultural regions (Munns and Tester, 2008; Zeng *et al*., 2001). Salinity affects over 20 % of global agricultural land and nearly one-third of irrigated areas, severely reducing productivity (Shrivastava and Kumar, 2015). One of the most harmful environmental conditions that reduces agricultural plant productivity and stifles a significant environmental threats to agriculture is salt stress. Farmers cultivate indigenous rice cultivars due to a lack of salinity-tolerant varieties, due to lower yield. Due to excessive salt concentrations, it is one of the main abiotic stresses that damage about 800 million hectares of land globally (Sackey *et al*., 2025). As a result, arable land is becoming frighteningly more salinized, which lowers the yield of once-productive soil globally. About one million hectares of Bangladesh's 2.85 million hectares of coastline land are significantly impacted by different salinities. An analysis of how salt stress affected plant growth showed a direct link between an increase in NaCl content and a reduction in plant length (Islam *et al*., 2023).

Because of the salinity of the soil and water (irrigation), between 30 and 50 percent of net-cropped fields in Bangladesh's coastal region remain fallow during the Rabi season. Climate change-induced salinity intrusion has had a disastrous effect on crop productivity in Bangladesh's saline regions. This situation necessitates an immediate response in order to increase crop productivity (Bhuyan *et al*., 2024).

Abiotic stresses can affect an organism's physiological status by impacting metabolic activity, reproduction, and maturity (Jnandabhiram and Borah, 2012), diminishing agricultural output (Bartels and Sunkar, 2005). Natural stresses are also the main reason of crop damage, lessening average interest rate for important crops by far more than 50 % and endangering the agronomic industry's long-term growth (Mahajan and Tuteja, 2005). High salt levels have a negative impact on processes like germinating seeds, seedling growth and vigor, vegetative growth, number of flowers, and fruit development, ultimately resulted in a reduced economic yield and productivity of crops. When exposed to various abiotic stresses, many plant species inherently generate nutrients and phenylalanine as natural bioactive osmotic adjustment. These compounds are thought to help stressed plants adapt by influencing osmotic adjustment and defending subcellular structures (Atta *et al*., 2023).

Salinity has surpassed drought as the second most popular soil issue in rice-growing regions of the world in recent years, and it has been regarded as a major threat. Salinity stress has a negative impact on agricultural yield all over the world, impacting production for both subsistence and profit (El-Goumi *et al*., 2014). The use of modern technologies has just been contributed to approximately 84 % of the raise in rice production. The primary trait for selection in drought tolerance breeding is grain yield under stress conditions. Because of the relationship between watering duration from flowering to physiological maturity, drought has an effect on seed yield. To help mitigate both cellular hyperosmolarity and ion disequilibrium, the plant's response to salinity is made up of a number of procedures which also too must work together (Adzigbe *et al*., 2025).

The world's population is rapidly growing, and by 2050, it is expected to exceed 9 billion people. As a result, the present condition necessitates an increase in food production in the near future to solve the food shortage problem (Bahar *et al*., 2020). Screening rice germplasms for their performance under salinity during germination and seedling growth provides a valuable approach to identify tolerant genotypes and understand physiological responses. Growth parameters such as germination percentage, mean germination time, root and shoot length, seedling dry weight, are commonly employed to evaluate salt tolerance at the early growth stages (Tahjib-Ul-Arif *et al*., 2018). The use of diverse germplasm collections is particularly important, as it allows the identification of novel sources of tolerance that can be utilized in breeding programs aimed at developing salt-resilient rice varieties (Sakina *et al*., 2016).

Therefore, the present study was undertaken to evaluate the effects of salt stress on germination and growth parameters of diverse rice germplasms. The findings will contribute to the identification of promising tolerant genotypes and provide a physiological basis for future genetic improvement of rice under saline environments.

Materials and Methods

Salt stress experiment

This study involved the preparation of four salt stress levels (0, 50, 100, 150 mM NaCl). Seeds of various rice varieties cultivated in different regions of Bangladesh

(BRRI Dhan-61, Shova, BRRI Dhan-56, BRRI Dhan-57) were sourced from the Molecular Genetics Laboratory, Department of Genetic Engineering and Biotechnology, University of Rajshahi. All types of healthy, uniform seeds underwent surface sterilization and were thoroughly rinsed with distilled water. The seeds were positioned in sterile petri dishes (9 cm in diameter), accompanied by two sterile tissue papers and supplemented with 5 ml of distilled water or the corresponding test solutions, as detailed in the experimental studies on water stress and salt stress. Each treatment consisted of ten seeds per petri dish, with three replicates conducted. Germination tests were performed under a 12-hour light and dark cycle, with minimum and maximum temperatures of 14 °C at night and 24 °C at day, respectively. A seed is deemed germinated when the radicle reaches a length of 2 mm. The germination percentage was assessed by daily counting the number of seeds that had germinated. On the 15th day, measurements were taken for root and shoot length, as well as early seedling fresh and dry weights. Shoot and root dry weights were measured following oven drying at 60 °C for 48 hours (Montaña *et al*., 2014).

After final count, germination percentage (GP) was calculated by the following formulae (Ruan *et al*., 2002):

$$GP\ (\%) = (\text{Number of germinated seeds} / \text{Total seeds tested}) \times 100$$

The shoots and roots were isolated, and the fresh weights were determined by measuring; after being oven dried at 60 °C for 24 hours, the dry weights were instantly taken.

According to each salt treatment, the fresh and dry weights, referred to the controlled, were calculated in percent, by the following equations.

Fresh weight (FW) percentage reduction:

$$FWPR\ \% = 100 \times [1 - (\text{fresh weight salt stress} / \text{fresh weight control})]$$

Dry weight (DW) percentage reduction:

$$DWPR\ \% = 100 \times [1 - (\text{dry weight salt stress} / \text{dry weight control})]$$

Relative water content (RWC):
The water content respective to the fresh weight was calculated as described by (Sumithra *et al*., 2006):

$$RWC\ \% = 100 \times [(FW - DW) / FW]$$

Salt tolerance index (STI):
It is quantified by the ratio, respectively to the controlled, of the total dry weight in salt stress, in percent, and calculated by the following equation:

$$STI = 100 \times (\text{Total DW salt stress} / \text{Total DW control})$$

Results

Effect of salt on germination percentage
At all salt stress levels, BRRI Dhan-56 had the highest germination percentage (93.33 %) when compared to other varieties (Shova and BRRI Dhan-57). Because of the increased salt stress conditions, the germination percentage decreased most relatively in all varieties. In response to salt stress, the sensitivity revealed a significant difference between the varieties. The influence of salt concentration on germination percentage was evaluated by comparing. According to Hakim *et al*. (2010), in particular with respect to the adverse effects with certain charged particles, higher salt concentrations lower the water possibility in the medium, inhibiting absorption of moisture by germinating seeds and lead to reduced plant growth (Hakim *et al*. (2010)). At 150 mM salinity level germination was noticed or witnessed in the sequence BRRI Dhan-56> BRRI Dhan-57> Shova. In 50- and 150-mM salinity stress levels showed the result to the 150 mM salinity stress. There is also variation in salinity tolerance among rice varieties at germination. According to Akbari *et al*. (2007), the main inhibitory factor that reduces seed germination is the osmotic effect produced by salinity (Akbari *et al*., 2007). Final germination percentage under different level of salt stress of four rice varieties are stated in Figure 1.

Effect of salt on initiation and completion of germination
At all psychological stress, BRRI Dhan-56 took 3 to 10 days to emerge, whereas Shova and BRRI Dhan-57 tried to take 4 to 11 days to initiate and complete. Shova showed delayed germination and started the germination day number 4 and seed germinated number showed constant after 12 days which was relatively delayed than other varieties. Effect of salt on initiation and completion of germination is shown

in Table 1.

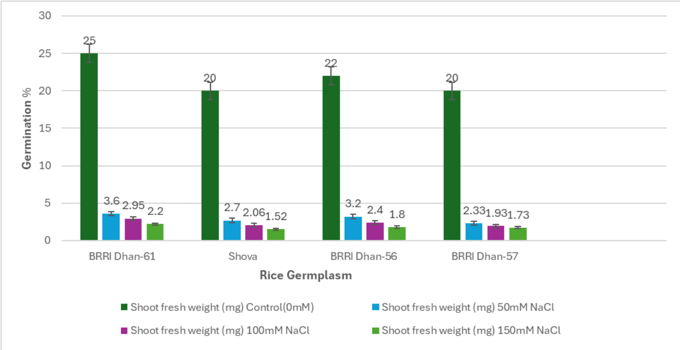

Figure 1: *Final germination percentage under different salt stress level.*

Table 1: *Effect of salt on initiation and completion of germination.*

Levels (mM/L)	Variety							
	Con (BRRI Dhan-61) (c)		Shova		BRRI Dhan-56		BRRI Dhan-57	
	I	C	I	C	I	C	I	C
50	3	7	4	11	3	8	3	8
100	3	8	4	10	3	9	3	9
150	3	9	4	11	3	8	3	9
0	4	8	3	11	4	8	3	7

I = initiation in days, C = completion days.

Effect of salt on shoot and root length

Plant height greatly reduced as salinity stress expanded, and BRRI Dhan-56 showed the greatest susceptibility to salinity stress. At all salinity levels, the BR-56 variety outperformed the other two varieties (Shova and BRDhan-57). Equally, as salinity stress risen, root length decreased. At each salt concentration level, salinity suppressed root length more than shoot length. BRRI Dhan-56 variety (6.23 cm) showed higher root length. In the way, BRRI Dhan-56 variety indicated higher shoot length (7.77 cm) at 50 mM/L NaCl level. But, due to the increment of salt stress the same variety showed less performance at 100 mM/L and 150 mM/L NaCl. The impacts stress on root and shoot length were significantly associated at the 0.05 percent probability value.

Shoot length is more affected in the variety of Shova compared with other two varieties (BRRI Dhan-56 and BRRI Dhan-57). Seedling height reduction is a common occurrence in many crop plants grown in saline conditions (Minh *et al.*, 2016). The length of shoots and roots reveals a lot about how plants react to stress of saline condition (Jamil and Rha, 2004). The shoot and root length of young plants developed in salt solutions diminished as well, revealing that salt stress directly impacted not only germination but also seedling growth, indicating that seed synthetic ability and thus seedling dry matter production have always been influenced. This is consistent with the investigation of Djanaguiraman *et al.* (2003) and Hakim *et al.* (2010), who discovered that salt had a significant effect on shoot and root length. Effect of salt on shoot length is shown in Figure 2 and effect of salt in root length is shown in Figure 3, respectively.

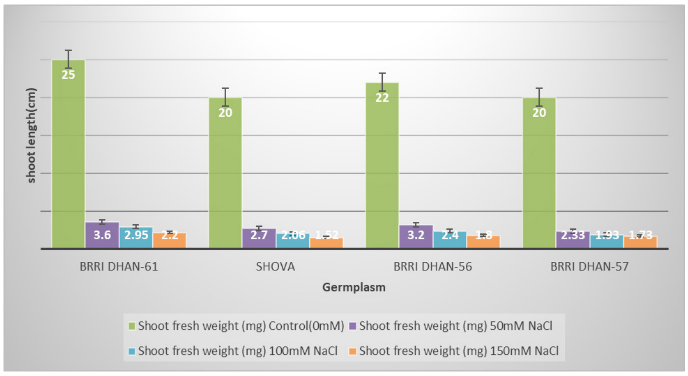

Figure 2: *Shoot length under different types of salt stress.*

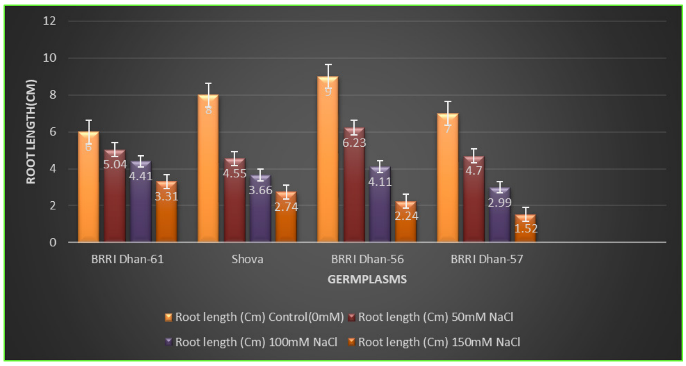

Figure 3: *Root length under different types of salt stress.*

Effect of salt on shoot and root dry weight

Shoot dry weight responded badly to salt stress which was less susceptible than root dry weight, particularly at greater salt concentrations. At 150 mM salt stress, BRRI Dhan-57 showed the largest reduction in shoot dry weight (1.73 mg), while BRRI Dhan-56 (5.47 mg) and Shova (4.93 mg) showed the minimal sensitive to saline condition. At all salt concentrations, the shoot dry weight of BRRI Dhan-56 was considerably less disturbed. The rate of decrease in fresh and dry weight was fairly smaller in the shoots than in the roots. Salt stress has been shown to mitigate seedling growth in a variety of other species (Achakzai *et al.*, 2010). On seedlings, salinity already has osmolarity and selective ionic influence (Dionisio-Sese and Tobita, 2000). Overall, the three varieties compared with control

(BBRI-61) and showed that BRRI Dhan-56 > Shova > BRRI Dhan-57 of shoot dry weight. The root dry weight exhibited results consistent with those of the shoot dry weight. The root dry weight of variety BR-56 was higher than that of the other two varieties (Shova and BRRI Dhan-57) when compared to the control variety BRRI Dhan-61. The impact of salt on shoot dry weight is illustrated in Figure 4, while the effect on root dry weight is presented in Figure 5.

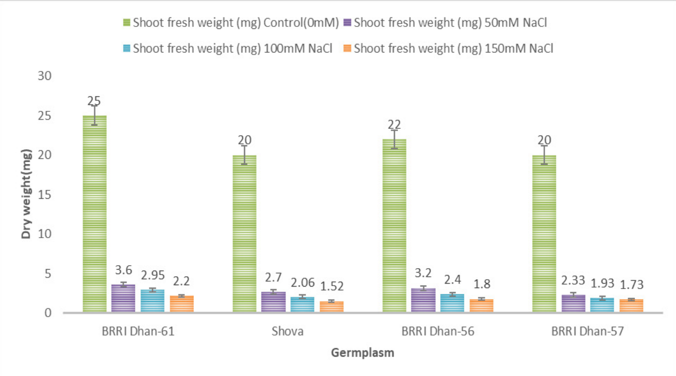

Figure 4: *Shoot dry weight under different level of salt stress.*

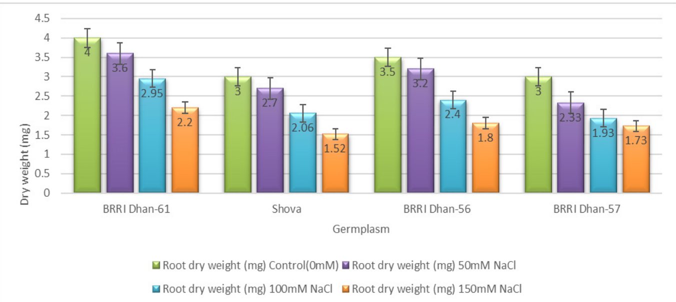

Figure 5: *Root dry weight under different level of salt stress.*

Effect of salt on shoot and root fresh weight

Data analysis of shoot and root fresh weight revealed that BRRI Dhan-56 outperformed other varieties (Shova and BRRI Dhan-57) when compared to the control variety (BRRI Dhan-61). The performance sequence was identified among these three varieties: BRRI Dhan-56 exhibits greater shoot fresh weight compared to Shova and BRRI Dhan-57. The performance decreased with increasing levels of salt stress.

Conversely, Shova exhibited superior performance in root fresh weight compared to other varieties. The serial activation results for root fresh weight are as follows: Shova > BRRI Dhan-56 > BRRI Dhan-57, in comparison to BRRI Dhan-61. The analysis indicated that optimal performance in root and shoot fresh weight was not observed in the same rice variety. Rice varieties were significantly affected by salt stress levels. The impact of salt on shoot fresh weight is illustrated in Figure 6, while the effect on root fresh weight is presented in Figure 7.

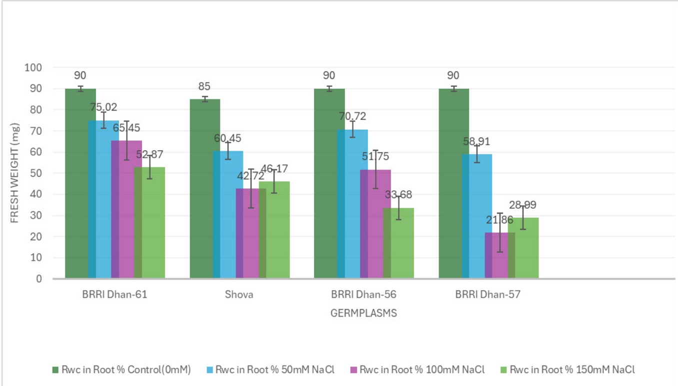

Figure 6: *Shoot fresh weight under different level of salt stress.*

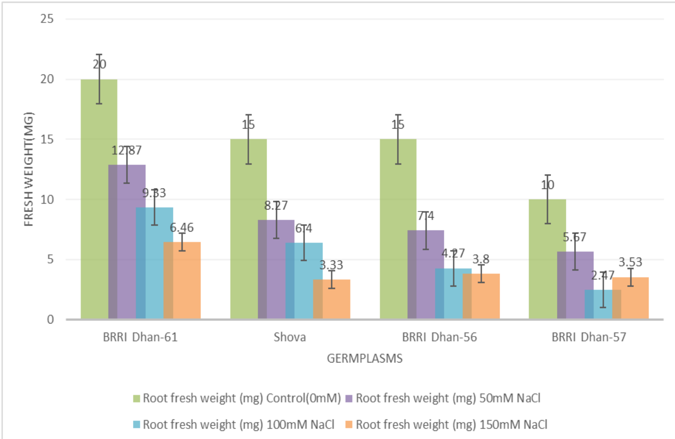

Figure 7: *Root fresh weight under different level of salt stress.*

Effect of salt on relative water content (RWC)

Relative water content refers to the amount of water in a leaf at the time of measurement, which is partially related to the maximum moisture capacity that the leaf can retain. This criterion is essential in water relevance analyses as it facilitates the estimation of osmotic potential under conditions of full moisture. Regarding the physiological effects of cellular water deficit, relative water content (RWC) is likely the most suitable indicator of plant water status. Water potential is significant for understanding water transport within the soil-plant-atmosphere continuum, as it quantifies the energy status of plant water. Leaf RWC is a critical component of plant water dynamics, as it seeks to equilibrate the water supply to young leaves with the rate of transpiration (Lugojan and Ciulca, 2011). Saline conditions significantly affected leaf water potential. RWC was diminished as a result of increased salt stress. The maximum relative water content was observed at 50 mM/L salt stress. BRRI Dhan-56 performed better under salinity stress because the relative water content of the shoot decreased as the salinity stress increased. However, when compared to the control variety BRRI Dhan-61, BRRI Dhan-56 performed significantly better in terms of root relative water content than other two varieties. In case of roots, BRRI Dhan-56 carried the large amount of water than other varieties (Shova and BRRI Dhan-57). Effect of salt on RWC of shoot is shown in Figure 8 and effect of salt in RWC of root is shown in Figure 9, respectively.

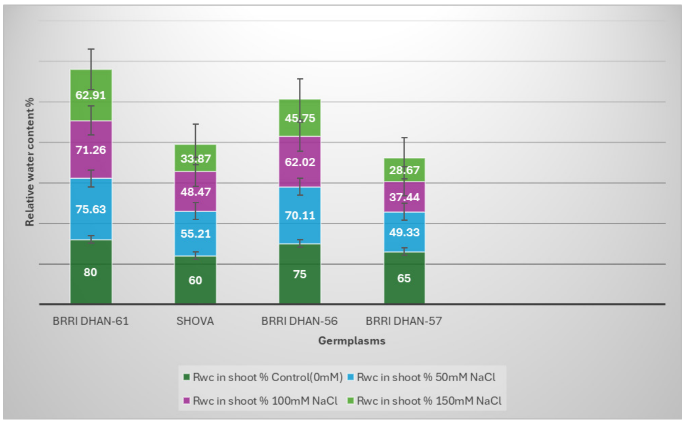

Figure 8: *Relative water content of shoot under different level of salt stress.*

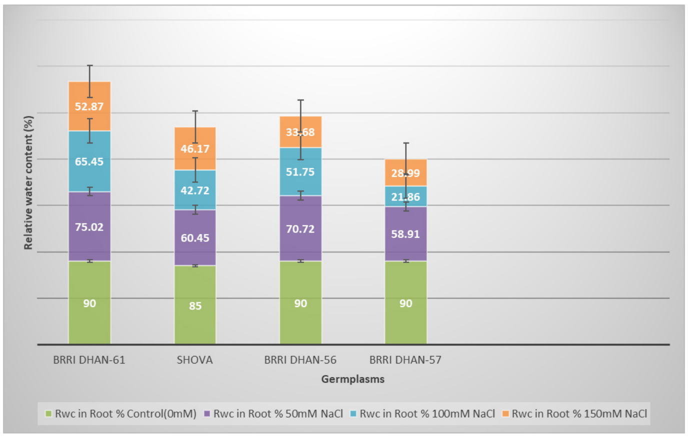

Figure 9: *Relative water content of root under different level of salt stress.*

Effect on salt tolerance index (STI)

The salt tolerance index lessened as salt concentration increased. BRRI Dhan-56 (92.47 %) had the highest STI, followed by Shova and BRRI Dhan-57. All varieties had the smallest salt tolerance at 150 mM salinity stress for shoot and root. Effect of STI on shoot is shown in Figure 10 and effect of STI on root is shown in Figure 11, respectively.

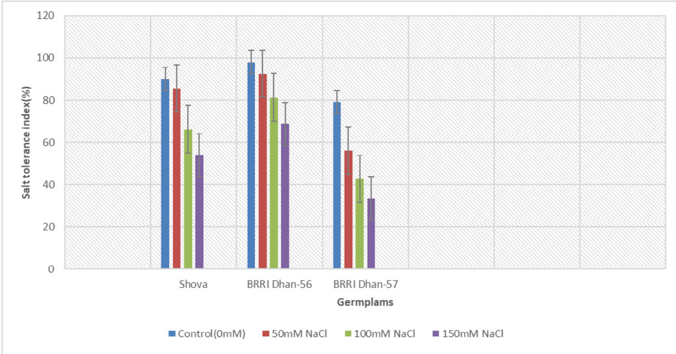

Figure 10: *Salt tolerance index in shoot under different level of salt stress.*

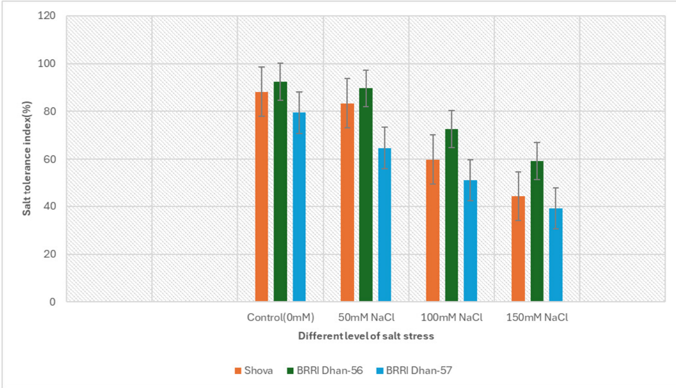

Figure 11: *Salt tolerance index in root under different level of salt stress.*

Discussion

The present study evaluated the germination and early growth responses of different rice (*Oryza sativa* L.) germplasms under varying levels of salt stress, providing insights into their relative tolerance and adaptability. The results clearly demonstrated that salinity had a significant inhibitory effect on seed germination, seedling growth, and vigor index across all tested germplasms, though the magnitude of inhibition varied among them. This variation reflects the genetic diversity in salinity tolerance mechanisms that exist among rice genotypes. Salinity primarily affects germination by imposing osmotic stress, which limits water uptake by seeds, and by inducing ion toxicity, especially through excessive accumulation of sodium (Na^+) and chloride (Cl^-) ions (Rana *et al*., 2008). In the present study, the decrease in germination percentage and germination rate under higher NaCl concentrations indicates that salt stress delayed or inhibited the enzymatic and metabolic processes required for germination. Similar findings were reported by Rahman *et al*. (2017), who observed that rice cultivars with higher osmotic adjustment capacity showed better germination under saline conditions(Tahjib-Ul-Arif *et al*., 2018).

The current findings demonstrate that increasing the concentration of NaCl hindered seed germination (Jamil *et al*., 2007). It has already been found to be enhanced salinity during the germination stage frequently causes an osmotic effect, resulting in a decrease in the volume of water absorption and/or selective ion toxicity, and may therefore mitigate germination percent (Huang and Redmann, 1995). The pathway of NaCl inhibition of germination and seedling growth, may be associated to insufficient water absorption and harmful effects on the embryo.

Al-Ahmadi and Kafi (2006) discovered that saline condition was negatively correlated to germination percentage (Al-Ahmadi and Kafi, 2006). There is also a variability in salinity response. The interaction of salt concentration and cultivars emphasizes this variability. Salt stress and tolerance in several species, such as rice which may include the expression of certain genes while repressing or entirely repressing the appearance of the others. These findings are in accordance with previous findings that indicate that multiple barley genetic traits respond differently to enhancing salt levels (Mano and Takeda, 1997).

Highest germination percentage was observed in BRRI Dhan-56 (93.33 %) compared with the other varieties in all salinity stress. BRRI Dhan-56 performed better than the other varieties likely due to its stronger physiological and biochemical tolerance mechanisms. This variety may possess enhanced osmotic regulation, allowing cells to maintain turgor and water balance under stress conditions. It may also exhibit more efficient ion exclusion, particularly restricting excessive Na^+ or other harmful ions from entering shoots and roots, thereby protecting metabolic processes. Additionally, BRRI Dhan-56 may have higher antioxidant activity, enabling it to reduce oxidative damage by scavenging reactive oxygen species. Together, these adaptive traits can explain its superior growth and biomass accumulation under the tested conditions. The sequence of germination performance was BRRI Dhan-56 > BRRI Dhan-57 > Shova which were compared with the control variety BRRI Dhan-61. The shoot length of BRRI Dhan-56 showed better results than other varieties, but in case of root Shova indicated quite better than BRRI Dhan-56. Root fresh weight was comparatively higher in Shova than other two varieties. So, both of shoot fresh weight and root fresh weight were not highest performance in the same variety. This indicated that salinity stress was impacted on different parts or organs of rice varieties variously. Furthermore, the measure of shoot dry weight was higher than other varieties. The maximum RWC was observed in Shova in 150 mM salinity stress. The serial performance of RWC was Shova > BRRI Dhan-56 > BRRI Dhan-57 for shoot, but different result showed in the root of all the varieties. The salt tolerance index indicates the tolerance ability varieties in salinity stress. Increasing NaCl concentration strongly inhibited rice germination and growth, consistent with previous reports (Lungu *et al*., 2011). Radicle growth may be slowed by saline conditions due to a decrease in radicle cell turgor. Overall, the present findings confirm that salinity exerts a negative impact on rice germination and growth but also reveal substantial genotypic variation that can be exploited for developing salt-tolerant cultivars. Future studies should focus on physiological and molecular analyses of tolerant germplasms to elucidate the mechanisms underlying salt tolerance, including ion transport regulation, Osmo protectant biosynthesis, and stress-responsive gene expression. So, this experiment may have great importance.

Conclusion

Rice varieties exhibited high sensitivity to salinity stress. The findings indicate that elevated salt stress adversely affects seed germination and initial seedling development across all rice varieties. However, the variation was significantly greater under high stress conditions for all physiological measures, including germination percentage, fresh and dry weight of roots and shoots, and lengths of roots and shoots, indicating germplasm disparity. The BRRI Dhan-56 variety demonstrated superior performance across the majority of physiological parameters. The BR-56 variety exhibited superior seed germination, relative water content, salt tolerance index, and seedling vigor. However, Shova demonstrated relatively greater root fresh and dry weight compared to the other two varieties. The salt tolerance ability among the varieties was ranked as follows: BRRI Dhan-56 > Shova > BRRI Dhan-57, in comparison to the control variety BRRI Dhan-61. These findings can guide breeding programs aimed at developing salt-tolerant rice varieties suitable for saline-prone areas of Bangladesh.

Acknowledgment

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Novelty Statement

This study evaluates the germination and early growth performance of various rice (*Oryza sativa L.*) germplasms under different levels of salt stress, identifying both salt-tolerant and salt-sensitive genotypes through physiological and morphological traits. Unlike previous studies that focused on single varieties or limited parameters, this research integrates multiple germination indices (germination percentage, vigor index, mean germination time) and growth parameters (shoot/root length, biomass, and stress tolerance index) to establish a robust screening method for salinity tolerance at the seedling stage. The findings contribute novel insights into the early-stage salt tolerance mechanisms of rice germplasms, offering valuable candidates and phenotypic markers for breeding programs aimed at improving rice resilience in saline-prone ecosystems.

Author' Contribution

RE: Writing original draft, writing review and editing, data curation.
FAZ: Data analysis, data collection.
MMO and PA: Data curation.
MAR: Formal analysis.
MRC: Writing- review and editing, supervision.

Generative AI and AI-assisted technology statement
The authors declare that no generative AI or AI-assisted technologies were used in the preparation, analysis, writing, or editing of this manuscript. All research design, data collection, analysis, and interpretation were conducted solely by the authors.

Conflicts of interest
The authors have declared no conflict of interest.

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