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MORPHO-PHYSIOLOGICAL TRANSFORMATION AND MITIGATION OF SALINITY IN RICE CULTIVATION

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Abstract

Bangladesh stands in third position globally in rice production where salinity is a significant abiotic stress that has a negative impact on rice which limit the crop production widely, affecting morpho-physiological characteristics of rice. Morpho-physiological characteristics such as plant height, root and shoot dry weight, leaf area index, number of effective tillers, chlorophyll content, net photosynthesis, transpiration rate etc. are reduces where Na^+-K^+ ratio, total soluble sugar, proline content increases under saline conditions. Panicle length, number of filled grains/panicle, 1000-seed weight, total yield etc. are also reduced under saline condition in rice. Therefore, rice productivity is threatened by predicted climatic changes with persistent salinity over time in the world. To overcome the threat, it is essential to realize the morpho-physiological changes in rice under salinity and the modifications that needed in rice cultivation practices like using of salt tolerant cultivars, crop rotation, scraping, flushing, leaching, mulching as well as water and nutrient management, soil amendments etc. should adapt to mitigate and to cope with the unfavorable conditions induced by salinity.

Keywords: Salinity, morphological, physiological, yield, cultivation, management etc

Introduction

A saline soil is usually the reservoir of a number of soluble salts such as Ca^{2+}, Mg^{2+}, Na^+ and anions SO_4^{2-}, Cl^-, HCO_3^- with exceptional amounts of K^+, CO_3^{2-}, and NO_3^-. Na^+ and Cl^- ions are considered the most important and both Na^+ and Cl^- are toxic to plants. A soil can be termed as saline if its EC is 4 dS/m or more which is equivalent to approximately 40 mM NaCl (Ghosh *et al*. 2016). The pH of saline soils generally ranges from 7-8.5. The arid and semi-arid zones are the most affected due to minimum lixiviation of salt, weathering of the parental rocks resulting in increased salt accumulation. Salinity is a well-off natural phenomenon occurring sea water flooding. However, use of improper irrigation and land clearing can be listed as one of the well-known anthropogenic reasons of salinity (Munns and Tester 2008).

Rice (*Oryza sativa* L.) is the most important cereal crop and a major staple food for the human populations worldwide with almost 16 million families in Bangladesh. Rice is regarded as most salt sensitive crop with threshold level of 3 dS/m exhibits varying degree of sensitivities among various varieties at different growth stages, specifically at the early vegetative and later reproductive stages and may cause more than 50% reduction in grain yield at 6 dS/m (Nam *et al*. 2015). The cause of rice injury in salinity is due to ionic toxic effect, osmotic or water stress and nutrient imbalance. These effects induce both morpho-physiological changes like plant height, root and shoot dry weight, leaf area index, panicle length, relative water content, chlorophyll content, net photosynthesis, transpiration rate, total soluble sugar, proline content etc. which are causing growth inhibition and yield loss.

The negative impact of salinity can be managed mainly by using salt tolerant cultivars with agronomic strategies like crop rotation, scraping, flushing, leaching, mulching as well as water and nutrient management, soil amendments etc. Keeping these above considerations in view, the present review has aimed to understand the effect of salinity on morpho-physiological characteristics of rice and to suggest the management strategies to mitigate the salinity effect in rice cultivation.

Transformations in morpho-physiological parameters of rice due to salinity

Salinity induces morphological and physiological changes like plant height, root and shoot dry weight, leaf area index, number of effective tillers, Na^+-K^+ ratio, chlorophyll content, net photosynthesis, transpiration rate, total soluble sugar, proline content, panicle length, number of filled grains per panicle, 1000-seed weight reduction, total yield etc.

Plant height: Plant height of different rice genotypes was influenced by salinity which may be due to the negative effect of salt on the rate of photosynthesis, changes in enzymatic activity and decrease in CHO and growth hormones (Khanam *et al*. 2018). According to the authors, at this stage, salt enters the cells through non-specific ion channels in the membrane, which lead to production of stress hormones and a reduction in cell division and growth (Chinnusamy *et al*. 2005). However, increased stress limits the cell wall elasticity, cell walls become rigid and consequently the turgor pressure efficiency in cell enlargement is decreased. (Ali *et al*. 2004). Increasing salinity at 5 and 10 dSm^{-1} plant heights reduced significantly (Fig. 1) (Islam *et al*. 2018).

Leaf area index (LAI): Salinity significantly decrease the production of green leaf and reduce leaf area index (LAI) (Fig. 2). It could be the negative effect of salt on photosynthesis that reduce plant growth and leaf growth (Khanam *et al*. 2018). The expected causes of the reduction in leaf area and yield components in rice could be the shrinkage of the cell contents, reduced development and differentiation of tissues, unbalanced nutrition and damage of membrane. The reduction can be also due to decreased

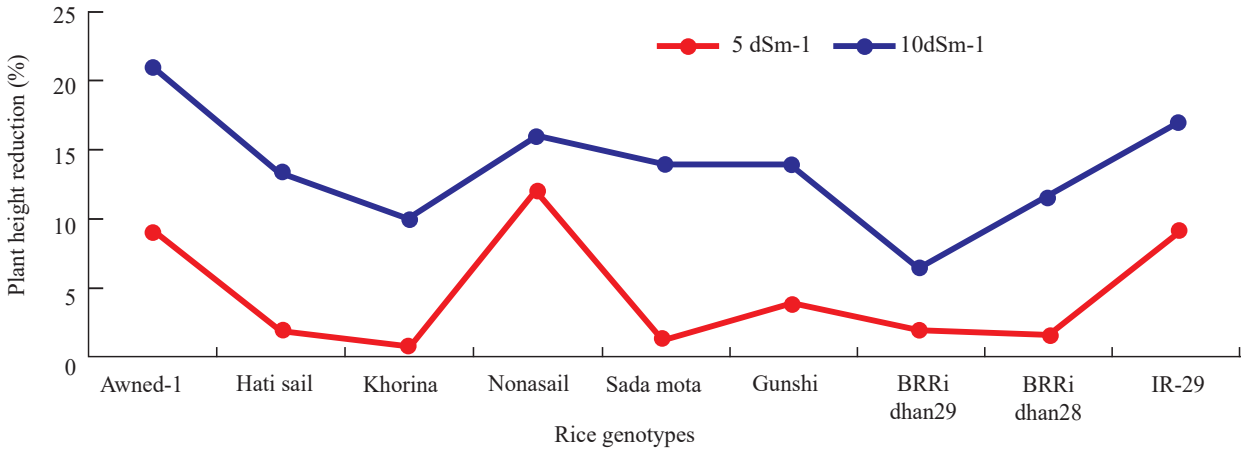


Figure 1. Plant height reduction (%) of rice genotypes under two salinity levels (Islam *et al*. 2018).

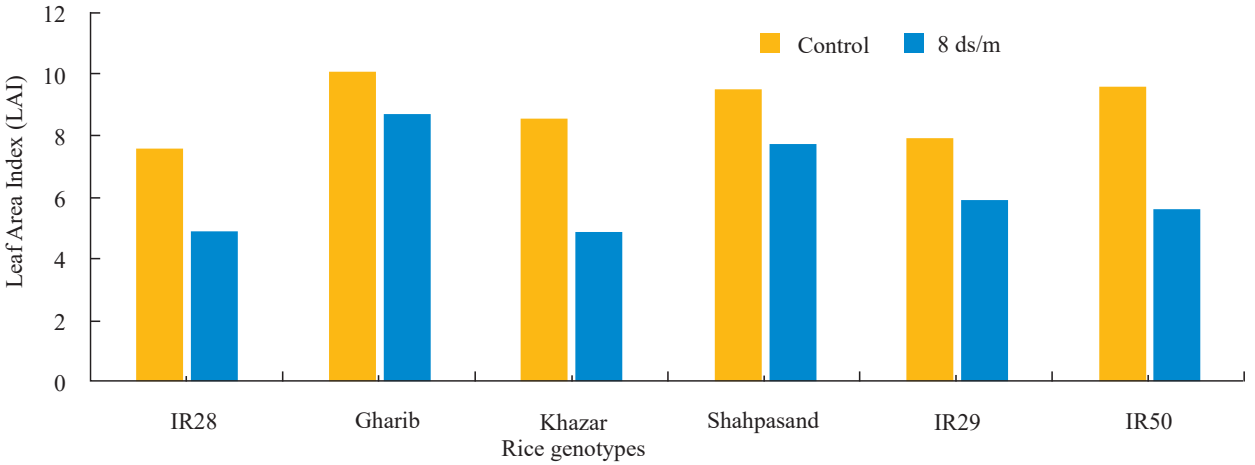


Figure 2. Effect of salinity on leaf area (LAI) of rice varieties (Gholizadeh and Navabpour. 2011).

water uptake, toxicity of Na^+ and Cl^- in the shoot cell as well as reduced photosynthesis (Ali *et al*. 2004).

Root and shoot dry weight: Significant decrease of shoot and root dry weight was recorded with increasing of salinity levels (Table 1). Hakim *et al*. (2014) reported that it might be due to (i) low photosynthesis, (ii) lower water potential and (iii) direct growth retardation due to disturbance in mineral supply (Shultana *et al*. 2019). Salinity caused a reduction in root growth (volume, area, diameter, total and main length and root dry weight), and shoot biomass accumulation with an increase of root/shoot ratio is often observed (Cécooli *et al*. 2011).

Number of effective tillers hill^{-1}: Different salinity levels had significant effect on number of effective tillers per hill. The maximum number of effective tiller/hills of all genotypes was found in control and the minimum was at 10 dSm^{-1} salinity level (Table 2). Due to salinity the effective tiller reduction was varied from 13.28 to 80.56% (Islam *et al*. 2018). It can be stated that the panicle formation and tillering stages were the most sensitive stages to salinity. The disturbance in reproductive and vegetation stages including tillering, heading and ripping reduces effective tillers under salinity (Rad *et al*. 2011).

Chlorophyll content: Chlorophyll 'a' content in rice showed different responses to salinity stress. Chlorophyll 'a' of some rice genotypes increased with salinity up to 40 mM NaCl, but decreased at higher salinity levels (Table 3). Chlorophyll 'b' and 'total' chlorophyll content decreased in all genotypes with increasing salinity because the biosynthesis of photosynthetic pigments get affected by NaCl (Kibria *et al*. 2017). Photosynthetic pigments are essential for light harvesting and, hence, for photosynthesis and plant growth. The decrease in chlorophyll content under salinity stress, caused by pigment photooxidation and chlorophyll degradation that may trigger the distortion of lamellae vesiculation and inactivation of photosynthesis (Rahdari *et al.* 2012).

Na^+-K^+ ratio: The ionic imbalances, which are developed by the accumulation of toxic ions, such as Na^+ and Cl^-, and the depletion of ions, such as K^+ and Ca^{2+}, are

Table 1. Salinity on root and shoot dry weight (g) of six rice varieties after harvest

Variety	Root dry weight (g)		Shoot dry weight (g)	
	Control	8 dS/m	Control	8 dS/m
Pokkali	1.15	0.61	4.52	3.49
BRRI dhan67	1.21	0.65	4.56	3.57
BRRI dhan47	1.23	0.58	3.95	1.66
Bina dhan8	1.20	0.53	4.14	3.17
Putra-1	0.95	0.41	5.14	1.93
MR297	1.08	0.19	5.04	1.47

dS/m = Deci Siemens per meter. (Shultana *et al*. 2019).

Table 2. Effective tiller hill^{-1} of rice genotypes under different salinity levels

Genotypes	Effective tillers hill^{-1}			
	Control	5 dSm^{-1}	10 dSm^{-1}	Reduction (%) at 10 dSm^{-1}
Awned-1	16.56	14.60	10.40	37.2
Hati sail	18.60	16.40	10.52	43.44
Khorina	15	9	7.60	49.33
Nonasail	18.60	18	9.40	49.46
Sadamota	19.40	18.80	10.20	47.42
Gunshi	20.60	15	9.60	53.4
BRRI dhan29	17.80	10.80	7.20	59.55
BRRI dhan28	16.20	9.20	5.80	64.2

dS/m = Deci Siemens per meter. (Islam *et al*., 2018).

Table 3. Effects of salinity on chlorophyll content in different rice genotypes

Genotypes	Chlorophyll a			Chlorophyll b			Total chlorophyll		
	Control	40 Mm	60 Mm	Control	40 Mm	60 Mm	Control	40 Mm	60 Mm
BRRI dhan28	4.53	4.11	3.60	5.19	4.22	2.38	9.72	8.33	5.98
BRRI dhan47	3.88	4.42	3.67	5.48	3.62	2.69	9.36	8.04	6.36
BINA dhan10	4.08	4.21	4.19	4.98	4.69	4.68	9.60	8.90	8.87
BINA dhan8	4.18	4.34	3.44	5.16	4.26	1.96	9.37	8.60	5.40

Mm = Millimole. (Kibria *et al*. 2017).

directly affected by salinity (Sumithra *et al.* 2006). The maintenance of Na^+ and K^+ homeostasis becomes more vital under salt stress. Plant exposed to salt stress is affected by Na^+ influx, which causes K^+ efflux and triggers K^+ and Ca^{2+} leakage from plant cells because plants uptake higher amount of Na^+ and show increasing Na^+/K^+ ratio (Figure 3) (Rahman *et al.* 2016, Shultana *et al.* 2019).

Photosynthesis and Transpiration rate: A reduction in total photosynthesis and transpiration rate was observed with increasing salinity in all the rice genotypes. (Figure 4). Under salinity stress, consequent reduction of the intercellular CO_2 concentration are the main causes of photosynthesis impairment. Salt stress also affects the efficiency of RuBisCO for carbon fixation, and the enzymes related to chlorophylls and carotenoid biosynthesis

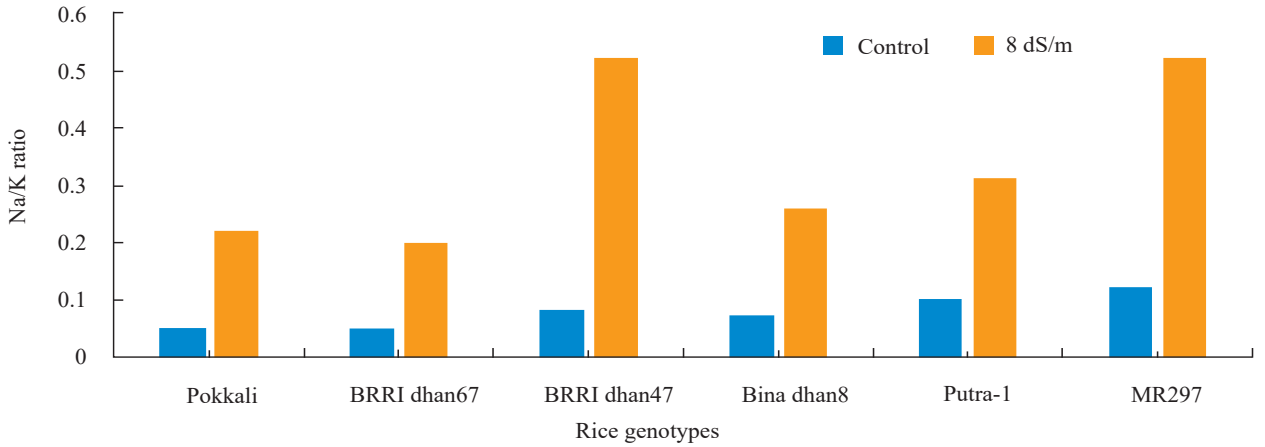


Figure 3. Effect of salinity on Na/K ratio of different rice varieties (Shultana *et al*. 2019).

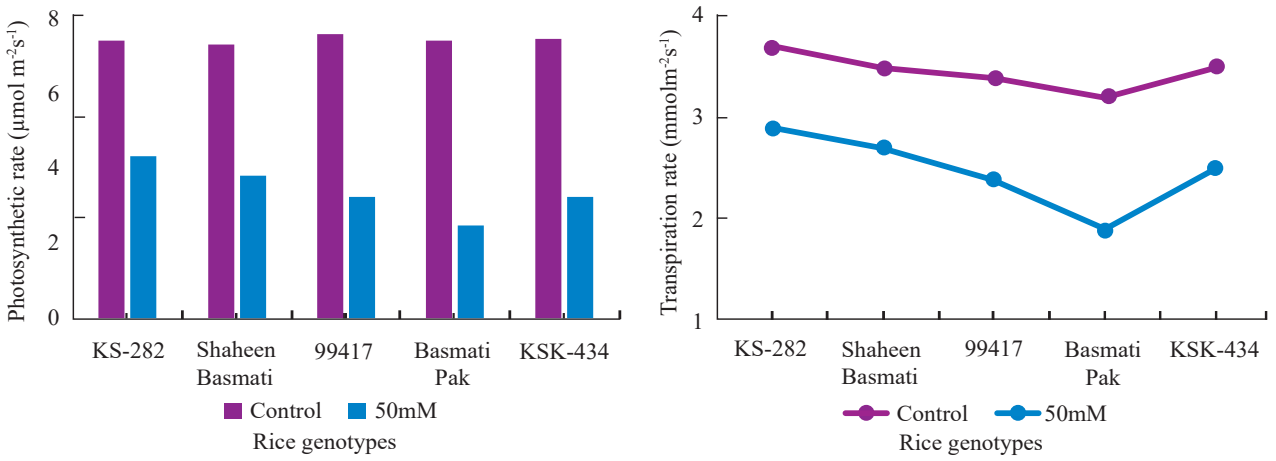


Figure 4. Effect of salinity on photosynthetic & transpiration rate of rice (Abbas *et al*. 2015).

(Chaves *et al*. 2009). Salt stress reduces the PSII activity and the quantum yield of PSII electron transport and affects the photosynthetic pigment-protein complexes (Demetriou *et al.* 2007). Reduction in transpiration may be due to higher Na^+ ion in the root and shoot zone that cause ionic imbalance, lower leaf area, low water uptake, low stomatal conductance, hampers stomatal opening, low chlorophyll content, lower photosynthesis and lower stored food (Abbas *et al*. 2015).

Total soluble sugar and Proline accumulation: Table 4 and figure 5 showed a positive correlation between salinity and total soluble sugar and proline accumulation (Polash *et al*. 2018).

Soil salinity initially hinders plant growth in the form of osmotic stress followed by ion toxicity (Munns and Tester. 2008). During the stress, root water absorption capacity diminishes and the leaf water loss is augmented because of osmotic stress and hyperionic stress with physiological alterations such as membrane disruption, nutrient imbalance, ROS detoxification, antioxidant enzyme activity and photosynthetic activity (Munns and Tester. 2008). It is well known that the accumulations and functions of compatible solutes, such as soluble sugars, proline, glycine betaine, and sugar alcohols, play an essential role in OA (Hare *et al.* 1998). These organic solutes stabilize and protect cellular membranes against dehydration, ROS scavenging system, buffer cellular redox potential, adaptively modify carbon allocation and regulate many metabolic processes (Shereen *et al.* 2020). As a result of such changes in carbon distribution, the accumulation of sugar in mature leaves is higher under salt stress.

Panicle length: Different salinity levels had significant reduction on panicle length of different rice genotypes (Table 5). Salinity affects plant physiology through changes of the water and ionic status in the cells and reduced panicle length (Islam *et al*. 2018). Under salinity, the changes of the size and seed yield of individual plants result from a combination of the competition within and among plants and salinity stress. Within plants, a

Table 4. Effect of salt stress on proline accumulation (µg g^{-1} fresh weight) of rice genotypes

Genotypes	Leaf proline content (µg g^{-1} fresh weight)		
	Control	100 mM NaCl	Increase (%)
Pokkali	10	20	200
Ashfal	11	23	209
Benapol	9	19	211
Jamainaru	9	17	188
Gunshi	6	17	283
Mohini	5	20	400
BRRIdhan29	4	20	500

µg g^{-1} fresh weight = microgram per gram fresh weight. (Polash *et al*. 2018).

Table 5. Panicle length of rice genotypes under different salinity levels

Genotypes	Panicle length (cm)			
	Control	10 dSm^{-1}	15 dSm^{-1}	Reduction (%) at 15 dSm^{-1}
Awned-1	29.80	22.30	19.88	33.29
Hati sail	24.26	20.11	17.39	28.32
Khorina	28.82	24.57	23.85	17.25
Soloi	17.42	15.85	14.78	15.16
Nonasail	22.90	19.31	17.22	24.80
Sadamota	27.18	25.34	22.67	16.59
Gunshi	27.82	24.63	21.32	23.37
BRRI dhan29	22.16	20.09	16.41	25.95
BRRI dhan28	22.74	18.21	15.66	31.14

dS/m = Deci Siemens per meter. (Islam *et al*. 2018).

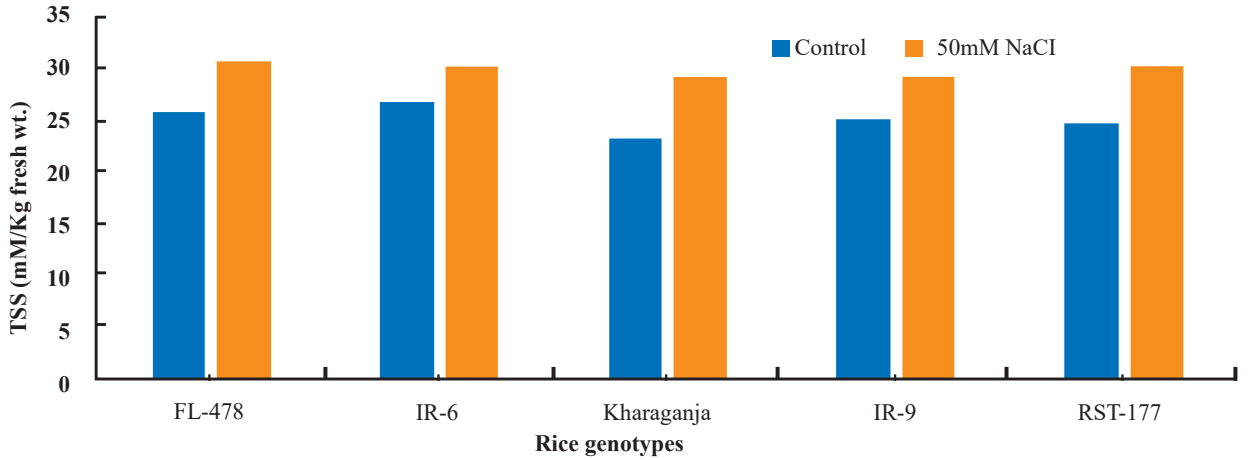


Figure 5. Effect of salinity on total soluble sugar of rice genotypes (Shereen *et al*. 2020).

source-sink relationship determines the partitioning of carbohydrates between vegetative and reproductive growth. The elongation of the culm at the same time as panicle initiation and development, can cause strong competition for carbohydrate supply resulted in the reductions in panicle length (Zeng and Shannon 2000).

Number of filled grains/panicle: Increasing salinity decreased filled grains/panicle of rice (Table 6) due to assimilate shortage during grain filling, reduced translocation of soluble carbohydrates and inhibition of starch synthetase (Islam *et al*. 2018). Sterility can be due to early leaf senescence, reduced translocation of soluble carbohydrates to spike lets, accumulation of more Na and less K in all floral parts and inhibition of the activity of starch synthetase in developing rice grains, thus reducing seed set (Aref and Rad 2012). It was also reported that reducing seed set in the panicle, possibly as a consequence of decreased pollen viability which is greatly influenced by the ionic toxicity under salinity (Mohammadi *et al*. 2010).

1000-seed weight reduction: Thousand seed weight of different rice genotypes was influenced by different salinity level (Figure 6). Salinity reduces the contents of photosynthetic pigments and soluble proteins in the ovaries that cause poor sugar production in ovaries and seed weight reduces (Islam *et al*. 2018). Mahmood *et al.* (2009) reported that grain weight of rice was least affected by salinity. Salinity effects on grain weight were actually brought about by reduced hull size, as evidenced by its dimensions and therefore took place already before flowering (Fabre *et al*. 2005).

Yield reduction: The yield of rice was significantly influenced by different salinity level. Salinity affects all the yield components and finally reduce the total grain

Table 6. Number of filled grainspanicle^{-1} of rice genotypes under different salinity levels

Genotypes	Number of filled grains/panicle			
	Control	5 dSm^{-1}	10 dSm^{-1}	Reduction (%) at 10 dSm^{-1}
Awned-1	110.01	95.71	83.27	24.31
Hati sail	80.82	70.31	61.17	24.31
Khorina	85.13	74.06	64.43	24.32
Nonasail	91.20	80.24	67.50	25.99
Sadamota	81.88	71.21	60.98	25.53
Gunshi	80.73	68.70	60.91	24.55
BRRI dhan29	114.43	101.51	85.67	25.13
BRRI dhan28	116.90	101.66	85.45	26.90

dS/m = Deci Siemens per meter. (Islam *et al*. 2018).

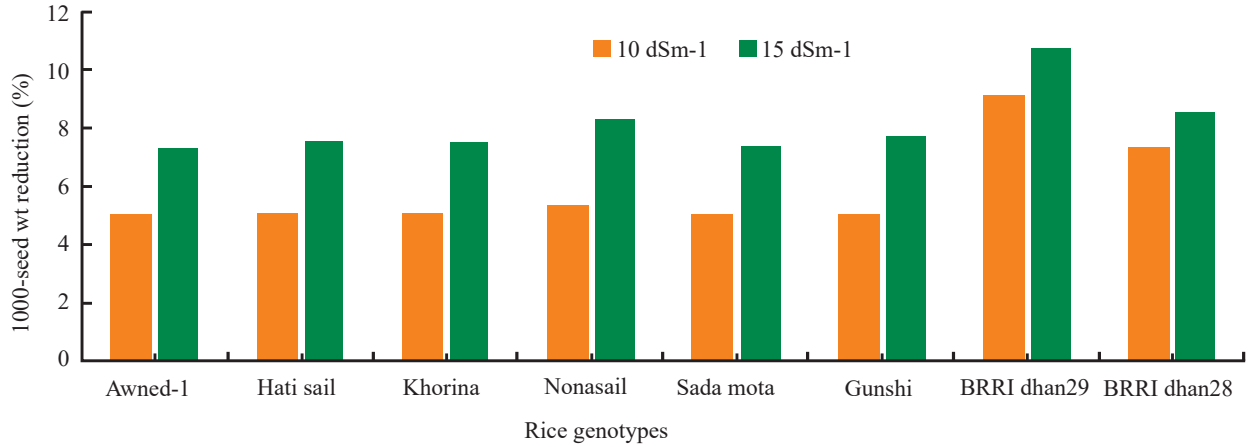


Figure 6. 1000-seed weight reduction (%) of rice under varied salinity levels (Islam *et al*. 2018).

yield in rice (Islam *et al*. 2018). The maximum seed yield of all genotypes was found in control and the minimum were at 10 dSm^{-1} salinities. Seed yield reduction was found more than 50% to 75% (Figure 7). Probably, the affected tiller number/hill, 1000-seed weight reduction and lower number of grains/panicles attributed for the reduced grain yield (Islam *et al*. 2018).

Management strategies to mitigate salinity in rice cultivation

The effect in rice for salinity can be managed mainly by using salt tolerant cultivars with agronomic strategies and nutrient management, soil amendments etc.

Growing salt tolerant cultivars: Salinity can possibly be managed through biologically manipulating the plants like identification of salt tolerant rice genotypes and incorporation of desirable traits into crop plants. BRRI and BINA developed some modern salt-tolerant cultivars such as BRRI dhan 47, 53, 54, 55, 61 and BINA dhan 8 and 10. These varieties possess salinity tolerance up to EC 8 dS m^{-1} in addition to high yield potential (> 4.0 t/ha), lodging tolerance and 10-38 days shorter growth duration over traditional rice varieties (Islam and Gregorio 2013). Development of BRRI dhan47, BINA dhan8, BRRI dhan53 and BRRI dhan55 for dry season was a major breakthrough for breeding salt tolerant rice in Bangladesh. BRRI dhan47 can tolerate EC 12 to 14 dS m^{-1} salt stress. The potential yield of the varieties ranged from 5.4 to 8.3 t ha^{-1} in different saline prone areas (Islam and Gregorio 2013).

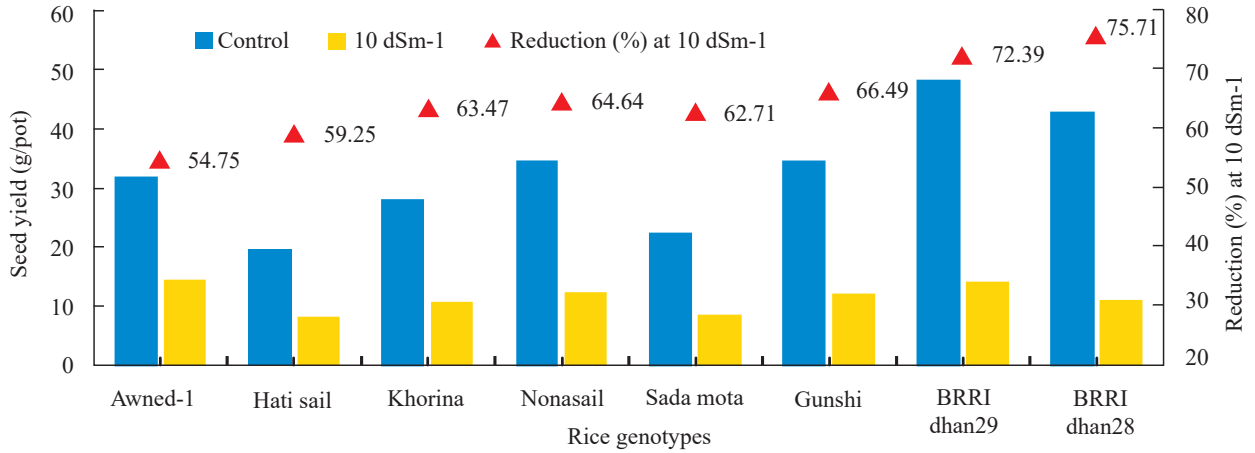


Figure 7. Yield (g/pot) and yield reduction (%) of rice genotypes under salinity (Islam *et al*. 2018).

Leaching and drainage: Leaching is the most effective method to reclaim saline soils. This requires good permeability of the soil and good quality irrigation water. For effective leaching need to apply enough water and a good drainage for the extra water and salts to go out. This extra water percolates through the root zone, carrying some of the extra salts out via natural or installed drainage system like drainage tile or plastic drainpipe. Cut drainage ditches in fields below the water table, drainage tile or plastic drainpipe can also be buried in fields for this purpose. The advantage of artificial drainage is that it provides the ability to use low salinity irrigation water to completely remove salts from the soil.

Irrigation: Rice plants are more susceptible to salt during germination or in the early seedling stages. An early-season application of good quality water to leach salts from the upper 6 to 12 inches of soil may provide good conditions for grow crop. Salts are most efficiently leached from the soil profile under higher frequency irrigation (shorter irrigation intervals). Keeping water between irrigation events effectively dilutes salt concentrations in the root zone (Ali *et al*. 2011). Sprinkler systems, particularly center-pivot and linear-move systems configured with nozzle packages or properly spaced drop nozzles and drip irrigation systems provide the best to salinity management.

Scraping and flushing: Removing the salts accumulated through capillary rise and subsequent evaporation in topsoil by mechanical means to minimize salinity and toxic effect of salinity is called scraping (Zaman *et al*. 2018). The mechanical removal is the simplest and the most economical way of reclaiming saline soils, if the area is small. This practice minimizes the salts temporarily; they will be accumulated again if there is a continuous feed of saline water to the soil surface. Flushing is suitable for saline soils which have surface salt crusts in arid and semi-arid areas and where rainfall is insufficient to leach the salts. This practice flushes the salts from soil surface and the flushed saline water then enters the drainage system. Once the water is ponded for a time which is sufficient to dissolve the salt crust, the ponded water can be flushed from the field, thus removing the surface salts.

Seed bed preparation: Generally, salts tend to accumulate on the ridges, away from the wet zone when furrow irrigation is adopted. Placing the seeds on the off-center slope (i.e., shoulder) of the single row will provide a location with minimum salinity. Under high salinity, the alternate row should be left un-irrigated. This will ensure maximum accumulation in un-irrigated area, leaving the irrigated furrows free of salts. Tillage can improve the soil's physical condition. Heavy and deep tillage with machinery can also mitigate the salinity where the salt goes down in the soil profile with irrigated water. Tillage with irrigation is most effective mechanical way to reduce salinity (Zaman *et al*. 2018).

Mulching: During periods of high evapotranspiration between two irrigations and during fallow periods there is a tendency for the leached salts to return to the soil surface. Mulching with crop residues or live crops reduces the evaporation from the soil surface and/or encourage downward flux of soil water that help to control root zone salinity. It reduces the upward pull of salts from ground water table (Creswell and Martin 1998). Crop residues are parts of plants left in the field after the crops have been harvested and threshed include stalks, stubbles or stems, and leaves have a significant reduction in soil salinity and higher leaching efficiency than bare soil.

Soil amendments: Soil amendments are most effective in alleviating salinity conditions in saline soils. Calcium amendments can replace Na^+ on the soil and improve soil structure. Gypsum ($CaSO_4$) is the most common amendment and may be used in acidic or alkaline soils. Lime may also be added and would raise the pH of an acidic soil. If soil contains "free lime", ($CaCO_3$), then adding an acid, like sulfuric acid (H_2SO_4), will liberate the Ca^{2+} in the soil to form gypsum. Appropriate application of Pyrites, H_2SO_4, $FeSO_4$ in soil also reduce salinity significantly by exchanging Na^+ ion with H^+ and Fe^{2+} ions (Table 7). The amount of amendment depends on the amount of exchangeable Na^+ ion present in the soil. The legume crops used for green manure, farmyard manure and cow dung add organic matter and also nitrogen into the soil. The decomposition of organic matter increases organic acids (humic, fulvic), which increase the solubility of calcium carbonate and mobilize calcium, thereby replacing exchangeable sodium from the soil and reducing soil salinity (Zaman *et al*. 2018). Organic amendments, when applied in conjunction with inorganic amendments can be more effective (van Zwieten 2018).

Crop rotation: Cropping systems are highly diverse, intensive and complex in Bangladesh. In recent years, rice-wheat, rice-maize, potato-rice-rice, wheat-rice–rice,

Table 7. Effect of different soil amendments.

Amendment	Soil characteristics	
	pH	EC (dSm^{-1})
Control	8.8	9.80
Gypsum	7.9	0.72
Pyrites	8.0	0.31
H_2SO_4	7.5	0.18
$FeSO_4$	7.9	0.85

EC (dSm^{-1}) = Electrical Conductivity in Deci Siemens per meter.

wheat-mungbean–rice pattern is increasing among farmers (en.banglapedia.org). Generally deep-rooted crops (jute) are grown after shallow rooted crops (rice) to suppress salt of the rice fields. Wheat rice crop rotation is considered best to salt management. Both crops produce the straw (wheat and rice straw) as residue which can potentially be used to control salinity issues. Foxtail millet can be a potential crop for salt affected soils in crop rotation with rice due to its high level of tolerance to salinity and the salt escape potential due to its short growing duration.

Conclusion

The morpho-physiological characteristics of rice are severely affected by salinity. Salinity reduces the morpho-physiological characteristics such as plant height, root and shoot dry weight, leaf area index, number of effective tillers, chlorophyll content, net photosynthesis, transpiration rate and increases Na^+-K^+ ratio, total soluble sugar, proline content etc. These morpho-physiological alterations adversely affect the yield and yield contributing traits such as panicle length, number of filled grains/panicle, 1000-seed weight, total yield etc. That's why, productivity of rice is affected severely. To cope with this and to get sustainable productivity for the increasing population rice cultivation practices should transform in a developed way to manage salinity. To manage salinity, we can use salt tolerant cultivars with crop rotation, scraping, flushing, leaching, mulching as well as water and nutrient management, soil amendments etc. Therefore, it is essential for us with our farmers to understand the morpho-physiological transformations in rice due to salinity to adopt the modifications that badly needed in rice cultivation practices in rice production to ensure food security in Bangladesh.

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