RESPONSE OF DIFFERENT GENOTYPES OF BORO RICE TO FOLIAR APPLICATION OF MICRONUTRIENTS UNDER SALINITY STRESS

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*This is to certify that thesis entitled, "**RESPONSE OF DIFFERENT GENOTYPES OF BORO RICE TO FOLIAR APPLICATION OF MICRONUTRIENTS UNDER SALINITY STRESS**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **MISKATH ISMI**, Registration no. **14-05877** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated:
Place: Dhaka, Bangladesh

Assoc. Prof. Dr. Md. Hasanuzzaman
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Dedicated

to

My Beloved Parents

And

Respected Research Supervisor

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BY

MISKATH ISMI

ABSTRACT

The field experiment was conducted at net house of the department of agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020 to evaluate the effect of foliar application of micronutrients for increasing salinity tolerance in rice plants. The experiment consisted of three factors. The factors were: factor A: Salinity level (2): S_1 = Control (No saline water) and S_2 = 150 mM NaCl; factor B: Micronutrients (4): M_1 = Control (No micronutrients), M_2 = Zinc (0.5%), M_3 = Boron (0.5%) and M_4 = Zinc (0.5%) + Boron (0.5%); factor C: Variety (5): V_1 = BINA dhan10, V_2 = BINA dhan8, V_3 = BRRI dhan29, V_4 = BRRI dhan47 and V_5 = BRRI dhan67. The experiment was laid out in a RCBD factorial design with three (3) replications. Results showed that the salinity stress-imposed plants S_2 (150 mM NaCl) were out-yielded by producing 58.23% lower grain yield than control plants S_1 (No saline water). The treatment S_2 (150 mM NaCl) also showed the shortest plant at harvest (78.69 cm), lowest tillers hill^{-1} (6.27), shortest leaf at harvest (28.50 cm), narrowest leaf at harvest (1.45 cm), shortest panicle length (18.56 cm), lowest filled grains panicle^{-1} (52.04), highest unfilled grains panicle^{-1} (17.07), maximum weight of 1000-grains (17.86 g), straw yield (21.69 g hill^{-1}), biological yield (42.40 g hill^{-1}) and harvest index (48.84%) in compare to control or no salinity stress-imposed plants. Significant differences existed among different levels of micronutrient applications with respect to yield and yield attributing parameters. A yield advantages of 5.28 g, 5.31 g and 10.94 g hill^{-1} over M_1 (No micronutrients), M_3 [B (0.5%)] and M_2 [Zn (0.5%)] applied pot, respectively was found which was possibly aided by taller plant (86.24 cm), higher tillers hill^{-1} (7.94), longer panicle (22.21 cm), maximum filled grains panicle^{-1} (67.79), lowest unfilled grains panicle^{-1} (12.19), highest weight of 1000-grains (20.93 g), straw yield (26.07 g hill^{-1}), biological yield (56.31 g hill^{-1}) and harvest index (53.70%) in the M_4 [Zn + B (0.5%)] treatment. On the other hand, treatment M_3 [B (0.5%)] gave similar results to M_4 treatment in some parameters like—plant height, tillers number, leaf length, unfilled grains panicle^{-1}, panicle length, weight of 1000-grains, straw yield, biological yield and harvest index. M_3 [B (0.5%)] or M_4 [Zn + B (0.5%)] treatment seemed promising in mitigating salinity stress in rice field compared to individual application of zinc or boron. Results also showed that V_5 (BRRI dhan67) exhibited its superiority to other tested variety BINA dhan10, BINA dhan8 and BRRI dhan29 in terms of seed yield, the former out-yielded over V_1 (BINA dhan10) by 13.34%, V_2 (BINA dhan8) by 1.27% and V_3 (BRRI dhan29) by 1.20 % higher yield. Interaction of $S_1V_2M_1$ (No saline water × BINA dhan8 × No micronutrients) performed better in most of the studied parameters. The $S_1V_2M_1$ treatment combination also showed better performance in terms of grain yield. Taking together these results suggested that B (0.5%) or Zinc (0.5%) + Boron (0.5%) combined application along with variety BRRI dhan29 and BRRI dhan67 showed better performance under salinity stress condition.

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL WORD
%	Percentage
@	At the rate of
AEZ	Agro-Ecological Zone
Afr.	African
Agric.	Agriculture
Agril.	Agricultural
Agron.	Agronomy
AIS	Agriculture Information Service
Annu.	Annual
Appl.	Applied
APX	Catalase
Aust.	Australian
B	Boron
BBS	Bangladesh Bureau of Statistics
BINA	Bangladesh Institute of Nuclear Agriculture
Biol.	Biology
Bot.	Botany
BRRI	Bangladesh Rice Research Institute
BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
Ca	Calcium
CAT	Ascorbate Peroxidase
Chem.	Chemistry
cm	Centi-meter
CV (%)	Percent Coefficient of Variance
cv.	Cultivar (s)
Cytopathol.	Cytopathology
DAS	Days After Sowing
DAT	Days After Transplanting
Dev.	Development
EC	Electrical Conductivity
Ecol.	Ecology
eds.	editors
Environ.	Environmental
et al.	et alia (and others)
etc.	et cetera (and other similar things)
Exptl.	Experimental
FAO	Food and Agricultural Organization
Fe	Ferrum (Latin name for Iron)

LIST OF ABBREVIATIONS (Cont'd)

ABBREVIATION	FULL WORD
g	Gram (s)
Geochem.	Geochemistry
GSH	Glutathione
HI	Harvest Index
Hortc.	Horticulture
HYV	High Yielding Variety
i.e.	id est (that is)
IAA	Indole-3-Acetic Acid
IE	internal efficiency
Int.	International
IRRI	International Rice Research Institute
J.	Journal
K	Kalium (Latin name for potassium)
kg	Kilogram (s)
L.	Linnaeus
LAI	Leaf Area Index
LOX	Lipoxygenase
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
m^{-2}	Per meter squares
MDA	Malondialdehyde
mg	Milligram
MG	Methylglyoxal
Mn	Manganese
MoP	Muriate of Potash
MSTAT-C	Microcomputer Statistical Package-C
NaCl	Sodium Chloride
Nutr.	Nutrition
P	Phosphorus
Pak.	Pakistan
Physiol.	Physiological
POX	Peroxidase
Progress.	Progressive
RCBD	Randomized Complete Block Design
RDW	Root Dry Weight
Res.	Research

LIST OF ABBREVIATIONS

ABBREVIATION	FULL WORD
RFD	Recommended Fertilizer Dose
ROS	Reactive Oxygen Species
SAU	Sher-e-Bangla Agricultural University
Sci.	Sciernce
Soc.	Society
SOD	Superoxide Dimutase
SPAD	Soil plant Analysis development
SRDI	Soil Resource Development Institute
t ha^{-1}	Ton per hectare
TDM	Total Dry Matter
Technol.	Technology
TSP	Triple Superphosphate
UNDP	United Nations Development Programme
var.	variety
Viz	*videlicet* (L.), Namely
Vm	Vermicompost
Zn	Zinc
μMol	Micromole

CHAPTER I

INTRODUCTION

Salinity is the major soil problem in rice cultivation especially saline prone coastal areas and it is a second most abiotic problem than the drought that limits rice growth and productivity worldwide. As a consequence of tropical cyclones and irrigation, salinity intrusion has been gradually extended toward the inland water and soil (Mahmuduzzaman *et al.*, 2014). The salinity stress affecting area is increasing daily and reducing crop yield by 22–50% of many regions in the world. Salinity stress is adversely affecting about 6% of total land and 20% of total irrigated land globally (Qadir *et al*., 2014). Salinity problem is more serious in the agriculture of South and Southeast Asia in which accounts for more than 90% of world rice production. The adverse impact of the saltwater intrusion is higher in the coastal belt than in any other part of Bangladesh. The coastal areas of Bangladesh cover about 20% of the total land and over 30% of the cultivated land while about 53% of the coastal areas are affected by salinity (Haque, 2006). At the southern part of Bangladesh, salinity is a serious threat to rice production and almost 1.06 million hectares of arable lands are affected by salinity (SRDI, 2010). Although agriculture is one of the significant sectors of the economy of Bangladesh and rice is the staple food of this country, rice production level still remains low in the south-west region of this country due to high salinity extent in crop land (Miah *et al*., 2004). The coastal areas are potentially suited for rice production but were left idle due to salinity problem as rice considered extremely salt sensitive (Kana *et al*., 2011).

Rice (*Oryza Sativa)* is a diploid belongs to the Poaceae family. It is an important cereal food crop cultivated and consumed across the world population and most of the Asiatic peoples (Singh *et al*., 2012). Rice is a staple food crop and gives 50–80% calories to the more than three billion peoples (IRRI, 2009). About 90%

of the rice is consumed in Asia, where it is a staple food for a majority of the population including 560 million people (Mohant, 2013). It is the staple food of not only Bangladesh. The slogan ‘Rice is life’ is most appropriate for Bangladesh as this crop plays a vital role in our food security and is a means of livelihood for millions of rural peoples. During the year 2019–2020, rice covered an area of 28213 thousand acres with a production of 36603 thousand m. tons (BBS, 2021). However, the global rice production needs to be increased from 560 million tonnes to 850 million tonnes by 2025 to meet the growing demand of rice. Rice yields are declining in post green revolution era mainly due to imbalance in fertilizer use, soil degradation, irrigation and weeding schedule, type of cropping system practiced, lack of suitable rice variety for low moisture adaptability and disease resistance (Prakash, 2010). In Bangladesh, the average yield of rice is about 3.21 t ha^{-1} (BBS, 2021) which is very low compared to other rice growing countries of the World, like China (7.056 t ha^{-1}), Japan (6.82 t ha^{-1}) and Korea (6.87 t ha^{-1}) (FAO, 2021). In Bangladesh, rice is grown under three distinct seasons namely Aus, aman and boro in irrigated, rainfed and deep-water condition. Aus, aman and boro which covers 80% of total cultivable area of the country (AIS, 2011). According to BBS (2021) Aus, Aman and Boro produced 2.75, 14.20 and 19.64 million metric tons of rice. Therefore, Boro rice is one of the most important rice crops for Bangladesh with respect to its high yield and contribution to rice production.

Since rice is recognized as a salt sensitive crop, there is a serious concern that rice growth and development of yield attributes are affected by salinity. Yield attributes related to final grain yield are also severely affected by root-zone salinity. Primary branches $panicle^{-1}$, panicle length, spikelet $panicle^{-1}$, number of filled spikelet and seed weight $panicle^{-1}$ are significantly reduced by salinity. However, appropriate salt tolerant modern varieties which can fit into the rice growing ecosystem in the coastal areas in Bangladesh would boost up the country’s rice production. BRRI and BINA have already released few modern salinity tolerant rice varieties namely BRRI dhan40, BRRI dhan41, BRRI dhan53 and BRRI dhan78 for Aman season but only one variety BRRI dhan47 for Boro season which cover large areas.

Salinity stress causes osmotic stress and oxidative stress, through increasing the assimilation of Na^+ ion and decreasing the Na^+/K^+ ratio due to lower osmotic potential within the plant roots. The salinity affects germination, seedling establishment, stunted plant growth, poor reproductive development, and ultimately declines the crop yield (Turan *et al*., 2009). Salt stress causes negative effects on metabolic processes, i.e. photosynthesis process, stomatal conductance, reduce transpiration, and synthesis of protein and nucleic acids. Salinity also alters the ultrastructural cell components, damages the membranous structure, increases the reactive oxygen species, and reduces the enzymatic activity, which limit the growth and yield of crops (Hasanuzzaman *et al*., 2014). Salinity stress demonstrates lower osmotic potential of soil solution and higher concentration of nutrients in the rhizospheres and creates nutrient imbalance in the plant system and ultimately reduce uptake of nutrients by plants (Hussain *et al*., 2018). However, under salinity stress conditions, the plants go through deficiency of micronutrients due to lower solubility of ions and thereby their lowered uptake capacity by plants (Marshcner and Romheld 1994). However, the salt induced damage in plant system could be improved by foliar application of different micronutrient (Noaman *et al.*, 2004). The reason being that foliar application of nutrients are easily available to plants compared to soil applied and, moreover, are not fixed or diluted in the large volume of soil under salinity stress conditions (Baloch *et al.*, 2008). The foliar application of micronutrients results in increased uptake of macro- and micronutrients from the rhizospheres because of proliferation of root growth (Abdalla and Abdel-Fattah, 2000).

Zinc is one of the most important essential micronutrients required for the biosynthesis of the plant growth regulator such as indole-3-acetic acid (IAA) (Fang *et al.*, 2008), carbohydrate and nitrogen metabolism, root cell membrane integrity (Weisany *et al.*, 2014) and tolerance to environmental stress conditions which leads to high yield and yield components (Mousavi *et al.*, 2018). Response of rice crop to applied Zn towards yield increments as well as grain Zn enrichment was observed in India (Singh, 2009), Bangladesh (Rahman *et al*., 2008) and Turkey (Cakmak, 2008). Zn deficiency causes multiple symptoms that usually appear 2 to 3 weeks after transplanting of rice seedlings; when leaves develop brown blotches and streaks that may fuse to cover older leaves entirely, plants remain stunted and in severe cases may die, while those that recover will show substantial delay in maturity and reduction in yield (Neue and Lantin, 1994). Zinc deficiency in rice decreases tillering, increases spikelet sterility and time to crop maturity (IRRI, 2000). Foliar application of Zn could decrease the adverse effects of salinity stress by preventing movement of Na^+ and/or Cl^- uptake or translocation. Previous studies showed that in the salt-affected soils, Zn application could alleviate possible Na and Cl injury in plants (Fathi *et al.,* 2017). Zn plays an important role in modulating the reactive oxygen species (ROS) by increasing the activity of antioxidant enzymes, such as superoxide dismutase (SOD) peroxidase (POX), catalase (CAT) and ascorbate peroxidase (APX), thereby counteracting the negative effects of reactive oxygen species (ROS) generated by oxidative stress under salinity conditions (Amiri *et al.,* 2016; Sharaf *et al.,* 2016). Zn plays an important role in chlorophyll biosynthesis and carbohydrates conversion to sugars and its deficiency depresses the photosynthetic capacity (Tavallali *et al.,* 2009; Samreen *et al.,* 2017). Zn has a fundamental role in the regulation of the stomatal aperture, which is accounted for the possible role of Zn in maintaining a high K^+ content in guard cells (Tsonev and Lidon 2012).

Boron (B) has a significant role in root and shoot elongation, sugar translocation, nucleic acid synthesis, pollen tube growth and development (Azeem and Ahmad, 2011). Furthermore, B is required for biosynthesis of enzyme indole-3-acetic acid oxidase and participates in cell wall integration and lignification (Azeem and Ahmad, 2011). Boron plays a fundamental role in increasing water use efficiency in plants under different abiotic stresses (Hrishikesh *et al.,* 2012). Exogenous application of B ameliorate the salinity in different crops by reducing the Na+ accumulation in plant cell and through improving the nutrient uptake and equilibrium which further enhanced the production by improving the yield attributes (Ibrahim and Faryal, 2014). B is an important micronutrient for plants to promote cell growth and development of the panicle (Garg *et al*., 1979). B is responsible for better pollination, seed setting and grain formation in different rice varieties (Aslam *et al*., 2002, Rehman *et al*., 2012), making it more important during the reproductive stage as compared to the vegetative stage of the crop and found 90% of the boron in plants is localized in the cell walls (Loomis and Durst, 1992). B deficiency symptoms in rice begin with a whitish discoloration and twisting of new leaves (Yu and Bell, 1998). Severe deficiency symptoms from rice include thinner stems, shorter and fewer tillers, and failure to produce viable seeds. Boron deficient stems and leaves were found to be brittle while boron sufficient leaves and stems are flaccid. Declining productivity trends in rice growing countries are due to the micronutrient deficiencies (Savithri *et al*., 1999). Boron deficiency is of particular importance since it affects the flowering and plant reproductive process and therefore directly affects harvested yield (Bolanos *et al*., 2004). The amount of protein and soluble nitrogenous compounds are lower in B deficient plants (Gupta, 1993). Boron can be satisfactorily applied to the soil to provide season long elevation of the B status of a crop.

However, effect of soil application of different macronutrients, such as potassium (K), phosphorus (P), and calcium (Ca) and micronutrients, such as Zn, Fe, B and Mn and their uptake have often been studied under optimum growth conditions of rice, but the effects of foliar application of Zn and B on rice growth and yield under salinity stress is still not well studied.

Based on the above proposition, the present research work was designed to evaluate the exogenous application of Zn and B on the performance of yield attributes and yield of some selected high yielding rice varieties under salinity stress conditions with the following objectives:

- To observe the performance of different HYV in Boro season under salinity stress conditions.
- To observe the impact of micronutrients on different salinity level on Boro rice and
- To observe the interaction effect of salinity level and micronutrients on growth and yield of Boro rice.

CHAPTER II

REVIEW OF LITERATURE

Salt stress is an important abiotic stress factor which decreases the crop yield and quality. About 23% of cultivated lands are saline all over the world (Hussain *et al.*, 2018). The direct effects of salt stress on plants are reduced photosynthesis, respiration, and nutrient assimilation as well as hormonal imbalance. Indirect adverse effect of salinity is oxidative stress, which is enhanced by the generation of reactive oxygen species (ROS) in stressed plants. The ROS production subsequently causes damage to macromolecules such as lipids, proteins, and nucleic acids and thus disturbs membrane permeability. Salt stress conditions adversely affected essential nutrient availability and consequently crop yield and quality. Nutritional disorders are very common under salinity due to non-availability of nutrients and their competitive uptake and transport in plants. Micronutrients can mediate adverse effects of salt stress. Micronutrients (Mn, Zn, Fe, B, Cu, Cl, Ni, Mo, etc.) play different roles in mediating salt stress due to their involvement in diverse mechanisms, i.e., reduced ion toxicity, maintenance of water balance, improved mineral uptake and assimilation, biosynthesis of compatible solutes plus phytohormones, modification of different gas exchange attributes, and decrease in oxidative stress plus modification of gene expressions. Research activities regarding salinity effect on rice in Bangladesh are limited and slower in progress. However, substantial works have already been carried out in this line in many countries of the world. In this chapter an attempt has been made to review the available information on the effect of micronutrients and salinity on growth, yield and yield component of rice.

2.1 Causes of salinity

There are various sources of salinity which adversely affect crop production in agricultural lands. The type of salt-source is of great importance, but the salt built-up in the root zone also depends on other factors like soil type, climate, and soil and crop management. For instance, a coarse-textured soil in a humid climate will have a good infiltration rate and sufficient rainfall to leach down salts to lower soil layers. On the other hand, the process of salt leaching is less effective in fine textured soils and under arid and semiarid conditions. Depending on soil parent material, location, topography, and climate, salinity may develop in an area due to the deposition of salts from one or more of the following sources.

2.1.1 Primary salinity

The salinity developed due to salty soil parent material is termed as primary salinity. Along with insoluble aluminosilicates, soil parent material may contain carbonates, bicarbonates, chlorides, sulfates and phosphates of calcium, magnesium, sodium, iron, manganese and aluminium. These salts are transported and deposited as a part of soil parent material. Besides that, in situ weathering of various insoluble minerals also provides cations and anions in the solution and results in an increase in soil salinity.

2.1.2 Irrigation water as a source of salinity

Normal field soil irrigated with salty water becomes saline within a few years (secondary salinization). Water with EC ≤ 1 dS m^{-1} is considered good for irrigation. However, depending on the type of soluble salts, a single 4-acre-inch irrigation with water of EC 1 dS m^{-1} can add about 260–300 kg of salts into the field soil. Besides salt concentration in water and amount of water per irrigation, the salt built-up in soil also depends on irrigation type and frequency, crop rotation, soil type, and climate. Sewage and industrial effluent used for irrigation purposes is also a source of secondary salinity. The EC of the effluent is mostly high and depends on the source. In some third world countries, the effluents are discharged into rivers and canals, which result in salinization of otherwise good-quality water (EC≈0.3–0.5 dS m^{-1}). The quality of underground water pumped for irrigation purposes varies greatly with inner stratum, location (nearness of some big water body like river, canal, lake, etc.), pumping depth, and climate. In arid and semiarid regions, underground water is mostly saline whereas in humid regions high precipitation may cause electrolyte dilution.

2.1.3 Coastal salinity

Sea water, having electrical conductivity as high as 50 dS m^{-1}, can cause a salinity problem in coastal areas. The possible ways sea water can reach the land are flooding during high tide, ingress through rivers and estuaries, ground water inflows and salt laden aerosols. The effect of flooding is mostly localized and limited to the coasts. Whereas, the other factors can salinize several kilometres in-land from coastal areas. By transporting salty sea water splash and dry salts off coastal land for large distances, air may develop salinity of about 20–200 kg ha^{-1} $year^{-1}$.

2.1.4 Other salinity sources

There are some other sources, which can contribute to minor extent in salt built-up on agricultural lands. One of them is the addition of chemical fertilizers and organic manures. Mostly pure salts are used as fertilizers and the minor role of their addition can be easily assessed. Whereas, salt addition with organic manures varies greatly with type and source of the manure. For instance, organic matter addition through sewage sludge or industrial waste would add more salts compared to that of farmyard and poultry manures. Rainfall could be another minor source of salinity to agricultural lands. Early showers after a long dry season can add a few kilograms of salts per hectare per annum. Owing to air pollution in urban and industrial areas, the contribution of rain may be significantly higher compared to that of rural areas and forests.

2.1.5 Salinization of rice fields

Lowland rice requires a lot of water. According to an estimation made by International Rice Research Institute (IRRI), 1432 L of irrigation water is needed to produce 1 kg of rice. To fulfil this high-water requirement, rice is preferably cultivated on fine textured soils with poor infiltration to facilitate water stand over the soil surface. Reduced infiltration is further assured by the blockage of soil pores through puddling. In these circumstances, a large portion of water from flooding evaporates leaving salts precipitated in the top soil. Next irrigation water, after solubilizing with the previously precipitated salts, offers a more saline environment for the crop. In this way soils under rice cultivation are more prone to salinity development compared to that of other crops.

2.2 Effect of salinity on rice

The effects of salinity on rice growth, development and yield are very severe, especially during the pollination and fertilization stages (Reddy *et al.*, 2017). Salinity generally results in delaying of the heading in rice which reduces other yield components (Grattan *et al.*, 2002). In addition, salt stress generally adversely affects seed germination, seedling growth, leaf size, shoot growth, root length, shoot dry weight, shoot fresh weight, number of tillers plant^{-1}, flowering stage, spikelet number, percentage of sterile florets, biological yield and grain yield (Figure 1; La¨uchli and Grattan, 2009). Problems of salinity can be ameliorated by leaching excess salts from the root zone, altering farm management practices and adopting salt-tolerant rice cultivars (Manchanda and Garg, 2008). A number of genes have been identified which control the salt tolerance trait of the rice plant (Chinnusamy *et al.*, 2005). Two principal mechanisms of osmotic tolerance and ion exclusion occur in the plants in response to salinity and, consequently, plant growth and yield are reduced (Munns and Tester, 2008; Paul, 2012).

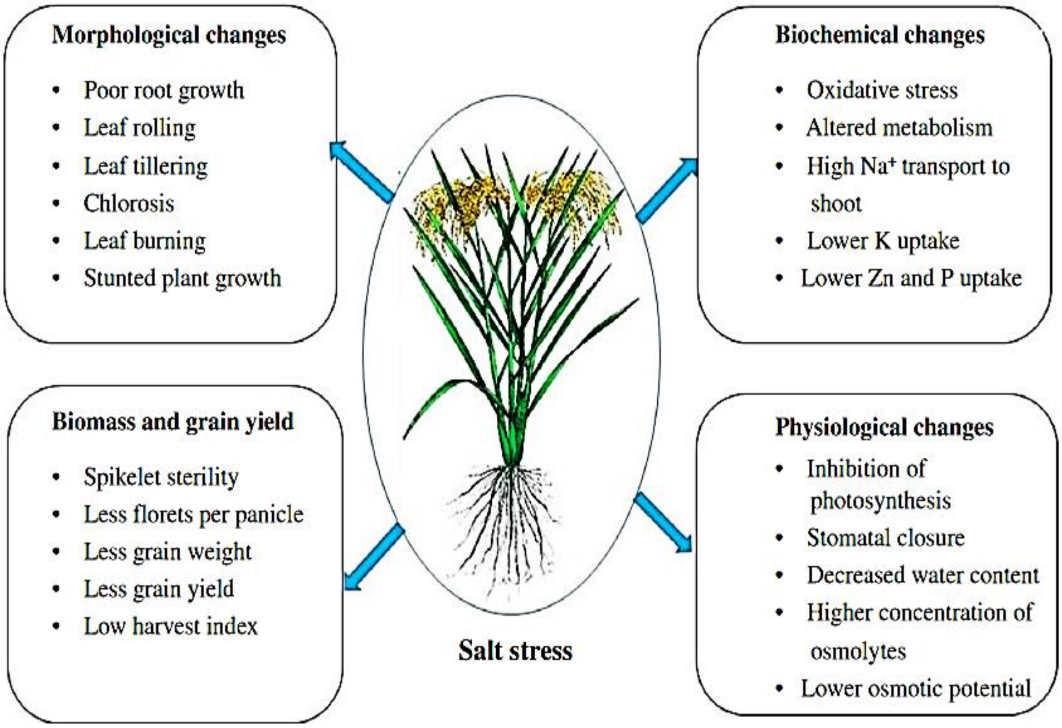

Figure 1. Schematic illustration of the multiple effects of salinity on plant growth, development, and yield attributes (La¨uchli and Grattan, 2009).

2.2.1 Germination

Seed germination is a parameter of the prime significance, and fundamental to total biomass and yield production and consists of a complex phenomenon of many physiological and biochemical changes leading to the activation of embryo (Parihar *et al.*, 2014). A significant negative correlation generally exists between the seed germination percentage, time for seed germination and level of salinity (Kaveh *et al.*, 2011). During seed germination, salinity results in many disorders and metabolic changes such as solute leakage, K^+ efflux and α-amylase activity (Shereen *et al.*, 2011). Firstly, salinity reduces moisture availability by inducing osmotic stress and, secondly, creates nutrient imbalance and ionic toxicity (Munns and Tester, 2008; Rajendran *et al.*, 2009). Cell membranes are the hotspots for controlling active and passive transfer of solutes, and regulating plant nutrient uptake (Munns and Tester, 2008). An imbalance of mineral nutrients under salinity stress generally alters the structural and chemical composition of the lipid bilayer membrane, and, hence, controls the ability of the membrane for selective transport of solutes and ions inwards and, the membrane could become leaky to the solutes they contain (Cushman, 2001; Lodhi *et al.*, 2009). Shereen *et al.* (2011) conducted experiments to study the effects of salinity on seed germination of six rice varieties differing in salt tolerance by treating them with 0, 50, 75, 100, 200 mM NaCl solutions. The results revealed that salinity caused a delay in germination of rice seeds with 3–6 days of delay in treatments containing 100 and 200 mM NaCl respectively, advocating a strong negative relationship between salinity and seed germination. The rice cultivators exhibiting minimal leakage of solutes showed relatively higher germination under high salinity stress of 100 and 200 mM NaCl compared to the cultivars exhibited higher solute leakage. Similarly, Jamil *et al.* (2012) investigated the effects of salinity on seed germination of three different rice genotypes and found that the rice cultivars differed in their germination response to salt stress. Increase in salinity from 0 to 150 mM adversely affected the seed germination percentage and significantly delayed seed germination.

2.2.2 Growth

Plant height is a fundamental plant morphological parameter which generally indicates changes in growth and development under any biotic and/or abiotic stress conditions. A number of studies have reported negative effects of salinity on plant height and shoot length. Salinity stress initiates stomatal closure which leads to an increase in leaf temperature and reduction in elongation (Rajendran *et al.*, 2009; Siraul *et al.*, 2009). Gain *et al.* (2004) studied the effects of salinity on BR11 rice cultivar using saline solutions of 0, 7.81, 15.62, 23.43, and 31.25 dS m^{-1} concentrations. The results showed strong negative effects of salinity on plant height and shoot length which consistently decreased with increasing salinity. They attributed these negative results to changes in the osmotic potential and the ability of rice to uptake water and nutrients. Similarly, Amirjani (2011) investigated the effect of salinity on morphological growth attributes of rice using 0 and 200 mM NaCl salinity treatments under controlled environmental conditions in a growth chamber. The results indicated 71% decrease in shoot length of plant under saline conditions compared to the control treatment, however, in contrast to the effects on shoot length, the root length showed a positive correlation with salinity (Amirjani, 2011). However, root length has been shown to differ markedly to salinity stress. In a study, P´erez-Alfocea *et al.* (1996) found an increase in root length after salinity stress and related this to the capability of the plant for the maintenance or even induction of root elongation at low water potential under salinity stress. These observations also suggested an adaptive strategy of plant roots under salinity stress and the ability of plants to reallocate the photosynthetic materials into roots while limiting their assimilation into shoot biomass.

2.2.3 Development

Salinity affects the leaf development by inducing changes in osmotic potential to reduce the ability of plants for water and nutrient uptake during the first phase. During this phase reduction in leaf area suggests a decrease in water intake to prevent the salt stress. During the second phase of ion toxicity, Na^+ accumulates in the leaf blade and transpiration stream, especially in the older leaves, which do not expand failing to dilute the ionic toxicity effect whereas, young leaves show expansion in response which lowers the toxicity of ions. This phenomenon leads to the death of the older leaves. When the older leaves die at a rate higher than that of the emergence of new leaves, the ability of plants for photosynthesis is greatly reduced which results in overall reduction in growth rate (Munns and Tester, 2008). Ali *et al.* (2004) performed a study to understand the effects of salinity on leaf and other yield parameters of 18 rice cultivars using an artificial saline soil medium. The results demonstrated a significant reduction in leaf area of rice plants with the increase in salinity levels. The leaf size depends on the processes of cell division and cell elongation. Results observed by Ali *et al.* (2004) for the reduction in the leaf area were attributed to suppressed cell division.

Gain *et al.* (2004) observed negative effects of salinity on plant height, biomass production and number of tillers plant^{-1} of BR11 rice cultivar grown at 0, 7.81, 15.62, 23.43, and 31.25 dS m^{-1} salinity levels. They found that the number of tillers increased from the control at 7.81 dS m^{-1} salinity but decreased thereafter at 23.73–31.25 dS m^{-1} salinity treatments. They concluded that the number of tillers production in rice could be less sensitive to salinity compared to the grain and panicle production. Salinity stress generally reduces both fresh and dry biomass of rice plant (Gain *et al.*, 2004; Amirjani, 2011). Growth reduction in rice plants when exposed to salinity stress occurs because of lower water potential in the cells leading to stomatal closure and limiting CO_2 assimilation (Lee *et al.*, 2003). Experiments conducted by Nemati *et al.* (2011) reported a reduction in biomass production of salt-tolerant (IR651) and salt resistant (IR29) rice varieties grown under salinity stress of 0 and 100 mM NaCl for 21 days up to the 6-leaf stage of development. However, under normal saline conditions, there were no significant differences among the cultivars. It was further observed that the decrease in dry weight was higher in the IR29 than in the IR651. Munns (2002) also reported a reduction in total biomass under salinity stress due to osmotic stress and inability for water uptake of the plant.

2.2.4 Yield attributes, Yield and harvest index

Salinity induces reduction in various growth and yield parameters of rice such as seed germination, plant height, number of tillers plant^{-1}, leaf area index, panicle length, number of spikelets panicle^{-1}, number of primary branches panicle^{-1}, percentage of fertility and 1000-grain weight (Abdullah *et al.*, 2001; Asch and Wopereis, 2001; Zeng and Shannon, 2000; Hasanuzzaman *et al.*, 2009). High soil salinity can also have a detrimental effect on crop stand establishment, chlorophyll concentrations, and causes delayed heading (Shereen *et al.*, 2005). Furthermore, K^+ content of shoot and K^+/Na^+ ratio can be reduced linearly while grain sterility and Na^+ content of shoot are increased with increasing soil salinity (Mahmood *et al.*, 2009). Although all these parameters are contributing, floret sterility, which reduces number of grains·panicle^{-1}, is considered to be the major cause of yield losses in rice under saline conditions (Shereen *et al.*, 2005; Mahmood *et al.*, 2009; Fraga *et al.*, 2010). The sterility, in turn, is correlated with sodium concentration in the panicles (Asch *et al.*, 1999). Salt-tolerant varieties have less sodium and more potassium in the panicle compared to that of susceptible ones (Asch *et al.*, 1999). However, sodium concentration in the panicle alone is not suitable to explain salinity-induced yield loss in rice (Asch *et al.*, 1999). Whereas, K^+/Na^+ in the leaves determined at about 60 days after sowing is a good criterion for predicting salinity-induced grain yield reduction (Asch *et al.*, 2000b). All growth and yield components of rice are negatively affected, in a quadratic manner, with increasing salinity in all periods of rice development (Fraga *et al.*, 2010). However, salinization between 3-leaf and panicle initiation stages is the most sensitive in terms of reduction in seed yield. For floodwater EC levels > 2 dS m^{-1}, a yield loss of up to 1 t ha^{-1} per unit EC (dS m^{-1}) is observed for salinity stress around the panicle initiation stage (Asch and Wopereis, 2001). On the other hand, reduction in shoot weight at maturity was prominent when plants were salinized before booting but not after that (Zeng *et al.*, 2001). Furthermore, the recovery from salt stress imposed at panicle development stage is difficult compared to that at vegetative stages (Asch and Wopereis, 2001).

The critical limit of flood water salinity above which rice grain yield is affected, strongly depends upon cultivar. According to Grattan *et al.* (2002), a salinity of field water more than 1.9 dS m^{-1} can reduce grain yield of rice. However, before their report the critical limit was thought to be 3.0 dS m^{-1} (Grattan *et al.*, 2002). Whereas, at and above 3.4 dS m^{-1} seedling survival become difficult for some susceptible rice cultivars (Zeng and Shannon, 2000). On the other hand, in some rice tolerant cultivars, grain yield is reduced by 25% only by flood water EC of 4.0 dS m^{-1} and not less than that (Beecher 1991). Furthermore, depending upon cultivar susceptibility, a flood water salinity of 8 dS m^{-1} can cause a 50% reduction in seed germination and an 80% loss of grain yield (Asch and Wopereis, 2001). In highly susceptible cultivars, the same level of salinity can reduce yields to nearly zero and dry-matter accumulation by 90% particularly in hot dry seasons (Asch *et al.*, 2000a).

2.3 Tolerance Mechanism of saline affected plants

2.3.1 Na^+/K^+ ratio

Growth and development of the plants are associated with the physiological responses that are associated with ion accumulation. Macro- and micronutrients essential to plants compete in their uptake and metabolism under salinity (Wang *et al.* 2003). Increase in specific ion accumulation like sulfate (SO_4^{2-}), chlorine (Cl^-) and sodium (Na^+) caused toxicity, which ultimately decreased the uptake of different nutrients like potassium (K^+), calcium (Ca^{2+}), P, and N. Plants are sensitive to high Na^+ plus Cl^- contents in soil, which ultimately decrease growth and yield. Tavakkoli *et al.* (2011) studied the toxicity effect of Na^+ plus Cl^- in four barley cultivars and observed a decrease in growth plus yield. High contents of Na^+ plus Cl^- in soil decreases the uptake and assimilation of K^+ plus Ca^{2+} which results in reduction of photosynthesis, stomatal conductance, and chlorophyll (Tavakkoli *et al.* 2011, Figure 2).

In *Atriplex griffithii* high Na^+ and Cl^- concentration was observed in leaves and then shoots and roots under salinity. This increment in Na^+ plus Cl^- decreases Ca^{2+}, K^+, and Mg^{2+} contents which shows the negative relation of these ions under salt stress and leads toward decrease of chlorophyll contents (Khan *et al.*, 2000). During the initial stage (seedling and primary vegetative stage), plant is particularly more sensitive to salt stress. Hasanuzzaman *et al.* (2009) observed that plant height, leaf area, and tiller number significantly decrease in the rice under salinity. Similarly, Guan *et al.* (2011) observed that plant height, length and number of branches, and shoot diameter decreased by more accumulation of Na^+ and Cl^- contents in *Suaeda salsa*. Dolatabadian *et al.* (2011) and Semiz *et al.* (2012) also observed substantial decrement of plant weight (root and shoot), number of leaves, plant biomass, and yield. However, many different mechanisms like restrictions in uptake and movement of salts in plants, maintenance of essential element ratio during salinity, and extrusion of salt from plants are involved for tolerance in salt stress to overcome toxicity of ions and withstand homeostasis (Parida *et al.,* 2004). Increasing NaCl concentration leads to the decrease of K/Na and Mg/Na ratios. The decrease may be attributed to increase of Na^+, which diminished concentration of K^+ plus Mg^{2+} due to antagonistic interaction. Consequently, K^+/Na^+ plus Mg^{2+}/Na^+ ratios in the roots and leaves showed high values and were reduced in the stem. In this respect, K/Na ratio might be considered as a tool of plant tolerance to salt stress.

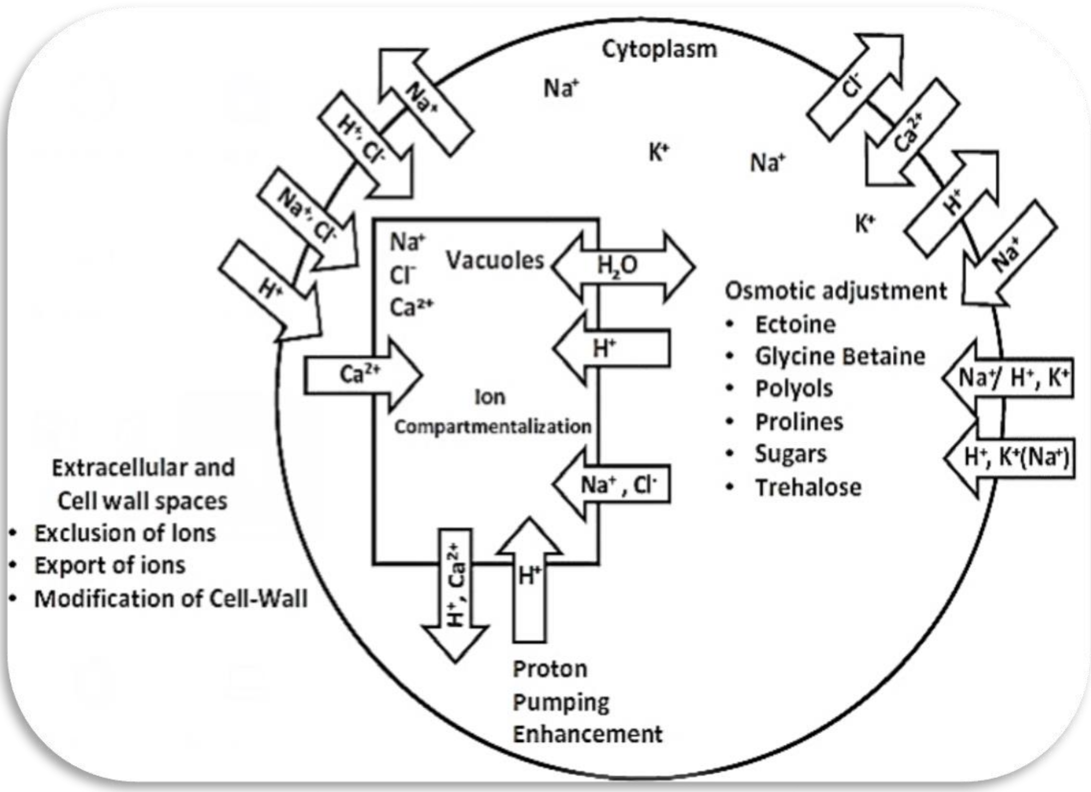

Figure 2. Three sections of plant cell. i) Extracellular and cell wall spaces, (ii) cytoplasm, and (iii) vacuoles. Na^+ and Cl^- movements across membranes and ion compartmentalization in vacuoles (Tavakkoli *et al*., 2011).

Under saline conditions, absorption and translocation of salinity-induced Na^+ and Cl^- competes with the nutrient elements such as K^+, N, P, and Ca^{2+} which generally develops a nutritional imbalance resulting in the reduction of qualitative and quantitative yield (Grattan and Grieve, 1999). Several researchers have reported accumulation of Na^+ and Cl^- ions in shoot tissues and, the resultant decreases in Ca^{2+}, K^+ and Mg^{2+} concentrations under the effects of increased NaCl contents in the rhizospheric zone (e.g., P´erez-Alfocea *et al.*, 1996; Khan *et al.*, 2000; Bayuelo-Jim´enez *et al.*, 2003). Plant growth reduction under Na^+ toxicity is the principal factor affecting plants as Na^+ is toxic to the cells of the majority of plants if present in the cytosol at a concentration greater than 10 mM. However, in contrast, K^+ is an essential nutrient for plants and required within concentrations of 100–200 mM for optimum metabolic functioning (Walker *et al.*, 1996, Taiz and Zeiger, 2002; Cuin *et al.*, 2003). More than 50 enzymes are activated by K^+ as a cofactor in cytosol, however, these enzymes are sensitive to high cytosolic Na^+ and high Na^+/K^+ ratios (Munns *et al.*, 2006). Therefore, in addition to low cytosolic Na^+ concentrations, maintaining low cytosolic Na^+/K^+ ratio is critical for the normal functioning of plant cells (Rubio *et al.*, 1995). When exposed to salinity, a dynamic competition takes place between Na^+ and K^+ for uptake as both are physico-chemically similar monovalent cations. Therefore, high levels of cytosolic Na^+ concentrations (higher Na^+/K^+ ratios), result in metabolic toxicity due to competition for the binding sites of many enzymes (Bhandal and Malik, 1988; Tester and Davenport, 2003). There is also the possibility that Na^+ can replace Ca^{2+} from the plasma membrane causing a change in plasma membrane permeability and integrity which can lead to K^+ leaking from cells (Cramer *et al.*, 1989). These biochemical changes from high uptake of Na^+ and K^+ leaking generally create an imbalance in the Na^+/K^+ ratio within the cytosol and affect enzymatic reactions in the cell.

2.3.2 Osmoprotectants (Proline, Betine)

During salt stress conditions, plant absorb more salts which decrease its osmotic potential. To cope with this problem, plants absorb inorganic salts like osmolytes and hydrophilic proteins that maintain osmotic relation. When plants are exposed to salinity, different osmolytes increased like proline and glycine betaine. To overcome these osmolytes, there is need of some enzymes, and under salinity, concentration of these enzymes also decreased (Pang *et al.*, 2010). Askari *et al.* (2006) found that these enzymes are involved in glycine betaine synthesis under salt stress: Sadenosylmethionine synthetase (SAMS) and betaine aldehyde dehydrogenase (BAD). Hydrophilic proteins including dehydrins have been observed to be elevated under salt stress (Kosová *et al.*, 2010). Salt-inducible LEA proteins, dehydrinTAS14, was observed by different scientists in tolerant genotypes of rice and tomato (Godoy *et al.,* 1994). Wu *et al.* (2013) also found that under salt stress, different compatible solute concentrations are increased like proline, glycine betaine, sugars, etc.

2.3.3 Micronutrients (Zinc and Boron)

Micronutrients improve plant tolerance against salt stress through activating some osmoprotectants. Iron, zinc, and manganese increase the proline concentration which can tolerate the effect of salts (Babaeian *et al.*, 2011). Iron also increases production of proteins under salinity (Jalilvand *et al.*, 2014).

a) Zinc

The amount of zinc (Zn) is generally 100 ppm in plant dry matter. Its uptake occurs in the form of Zn^{2+}. It is a constituent of more than 70 metabolic enzymes. It works in biochemical processes such as cytochrome, nucleotide synthesis, auxin, metabolism, and maintenance of membranes. The carbonic anhydrase enzyme is activated by Zn^{2+} ion. The enzymes such as alcohol dehydrogenase, oxidoreductases, hydrolases, transferases, isomerase, lyases, and ligases also regulated in the presence of Zn^{2+}. The application of zinc mitigated the negative effects of salt stress due to inhibition and uptake of Na+ and/or Cl− from the soil. The grain yield of wheat was improved by 16% through foliar feeding of zinc (Yruela 2009).

b) Boron

Boron (B) is present in an undissociated form in the soil solution and is taken up by plant in the form of H_3BO_3 and $B(OH)_3$. The amount of boron is generally 0.2–800 ppm and requirement are 20 ppm. It is relatively immobile in plants and is not component of other enzymes. Boron is involved in nucleic acid, protein and RNA metabolism, photosynthesis, and cell membrane stability. Deficiency of boron affects meristematic growth. It works in cell division, flowering, pollen germination, salt absorption, and water relations. The presence of B improves the uptake of K by plants (Malvi 2011). Its deficiency causes infertility, smalling of leaves, and poor yield (Davis *et al.* 2003). In the absence of boron, there are no fertilization and production of seed in some crop plants. Zinc, copper, and boron are involved in synthesizing of lignin, which is used to strengthen cell walls of biological membranes (Osakabe *et al.* 2014).

2.4 Effect of salinity on Micronutrients

In plants, relation between uptakes of mineral nutrients under salt stress is multifarious. Salinity affects the availability of nutrients, their uptake, and transport within plant. Salt stress decreases uptake of mineral nutrients, which strictly affects crop productivity (Rogers *et al.* 2003; Hu and Schmidhalter 2005). The uptake and assimilation of micronutrients under salt stress depend upon genotype and salinity level (Oertli 1991). There are many factors affecting the availability of micronutrients under salt stress. Under salt stress conditions, micronutrient availability depends upon micronutrient solubility, soil solution pH, redox potential, and nature of binding sites. In saline soils, micronutrient solubility is predominantly low, and plants frequently experience deficiencies, however not in all cases (Page *et al.* 1990). High pH is the major factor, which causes deficiency on micronutrient. The micronutrients are most available under the soils having less pH. In high-pH soils, there is less availability of ions like Fe, Mg, Zn, and Cu. Under salt stress, pH of soil is elevated, and availability of micronutrients becomes less because the ionic form of micronutrients is transformed to the oxides or hydroxides. Under salinity by maintaining soil pH, we will enhance the uptake and assimilation of micronutrients to plants. Salinity increases the concentration of Zn in citrus (Ruiz *et al.* 1997), maize (Rahman *et al.* 1993), and tomato (Knight *et al.* 1992), while decreases Zn in cucumber leaves (Al-Harbi 1995). It has been reported that under salinity, Fe, Mn, Cu, and Zn were higher in roots than leaves and stem in soybean (Tunçturk *et al.* 2008).

2.4.1 Effect of salinity on Boron

Salinity aggravates B toxicity symptoms in several plant species. Saline irrigation water often contains high boron concentrations and contributes to an accumulation of excessive levels of soil B (Nable, Banuelos & Paull 1997). Salinity has been reported to aggravate B toxicity symptoms in a variety of plant species, sometimes accompanied by an increase in total shoot B concentrations (Grieve & Poss 2000). More often, however, increased B toxicity symptoms occurred while total shoot B concentrations were not affected or even reduced, such as in chickpea (Yadav *et al.*, 1989), wheat (Bingham *et al.* 1987; Manchanda and Sharma 1991), eucalyptus (Grattan & Grieve 1999) and in stems of Prunus rootstocks (El-Motaium, Hu and Brown, 1994). No explanation is currently available for these contradictory observations. Generally, there is only a poor correlation between the expression of B toxicity symptoms in leaves and overall shoot B concentrations (Jefferies *et al*., 2000). Boron toxicity is often compared with the associative problems of excessive salts accumulation (Gupta, 1993) and usually found at toxic levels in saline and sodic soils (Hutchison and Viets, 1969).

2.4.2 Effect of salinity on Zinc

Salinity adversely affect crop performance by altering nutritional disorders like availability of micronutrients, competition in their uptake, assimilation, and movement in plants. Salinity increases level of sodium (Na) and chloride (Cl) ions in plant which have direct impact on concentration of other micronutrients. Uptake and movement of Ca in plant are decreased by increase in the concentration of Na, which affects yield and quality (Grattan and Grieve, 1999). Under salinity, micronutrient concentration varies in different plant species. Mn and Zn concentration are increased in barley, tomato, and rice under salinity whereas decreased in corn shoot (Hassan *et al.*, 1970; Mass *et al.*, 1972). El-Fouly *et al.* (2002) observed the increment of Zn concentration in the roots of tomato under salinity. The leaves of two mango rootstocks (Gomera-1 and Gomera-2) under salt stress showed increment in Mn, Fe, Ca, Zn, P, K, and Cu while decrement in Mg concentration. Similarly, Ca, Mg, N, and Cu contents are increased in stem, but Zn contents decrease in stem. The concentration of micronutrients is more in fibrous roots as compared to main roots (Zuazo *et al.,* 2004). The micronutrient uptake was different in plant organs when grown under saline environment. Furthermore, in soybean, the concentration of Fe, Mn, Cu, and Zn was more in roots as compared to leaves plus shoots (Tuncturk *et al.,* 2008). Salt stress also imposes drought which can also affect nutrient uptake and assimilation. Under severe salinity, the plant growth and yield are not increased by increasing nutrient concentration in soils, because under salt and drought conditions nutrient uptake is low. Hence, understanding the role of micronutrients in plant resistance to salinity will help to improve the fertilizer management in arid plus semiarid areas (Hu and Schmidhalter, 2005).

2.5 Mitigation of salinity stress by foliar application of Zinc and Boron

The deficiency of micronutrients is corrected either through soil or foliar application. The rationale for the use of foliar fertilizer includes (a) the availability of soil applied nutrient is limited, (b) having loss of soil applied nutrients, and (c) environmental conditions limiting application through soil medium. Under these conditions, the decision for foliar application is determined by the magnitude of financial risk and gathering the yield target (Fernandez and Brown 2013). However, foliar application is considered with regard to performance of mineral elements, their rates of absorption, and mobility within plant organs (Fernandez and Brown 2013). For example, boron has equivalence to urea absorption but has limited translocation within the plant (Will *et al.,* 2011). The translocation of boron is also limited in horticultural crops, and absorption is localized (Brown and Shelp, 1997) while it is generally absorbed in cereal crops (Kutman *et al.*, 2012). The foliar feeding of crop is being practiced extensively due to presence of high soil pH, salinity, and calcareousness of soils (Zhao *et al.*, 2014). Recently, nanoparticles containing micronutrients are being effectively used for foliar application, which are cost-effective, and to avoid environmental pollution (Kumar *et al.*, 2013). The size of nanoparticles is less than 100 nm; thereby, its decreased size results increased specific area of nutrients. The dissolution rate of low-solubility chemicals, e.g., zinc oxide, is increased (Alloway, 2009). Spraying plants with a micronutrient compound after salinity treatment leads to the reduction of Na concentration in roots and leaves, while it was increased and accumulated in the stems (El-Fouly *et al.*, 2010). Foliar sprays of micronutrients under salinity increase the ability of roots for selectivity of potassium plus magnesium ions, which allows transportation maintenance of both ions and limitation of sodium ion uptake in the shoots (Tattini *et al.*, 1993; Carvajal *et al.*, 1999). Micronutrient foliar application enhanced the root growth and decreased the nutritional disorder symptoms (El-Fouly *et al.*, 2010). It increases the uptake of micronutrients in roots and decreases the effect of salt. El-Fouly *et al.* (2002) described foliar application of micronutrients increased the nutrient uptake under salinity. Micronutrient foliar sprays showed positive effects with different degrees on micronutrient uptake when sprayed either before or after the salinization treatments. Exogenous application of micronutrients can mediate adverse effects of salinity by improving root growth, preventing nutritional disorders, and therefore increasing uptake of nutrients (El-Fouly *et al.*, 2002). Spraying plants with a micronutrient compound after salinity treatment leads to a reduction of Na concentration on roots and leaves, while it was increased and accumulated in the stem. Micronutrient foliar applications lead to the decrease of Na^+ ion concentrations. This may contribute to the reason that micronutrients have a regulatory mechanism and/or a control function on Na uptake and translocation rate. Micronutrients may be involved in integrity plus function of bio-membrane in plants (Thalooth *et al.*, 2006).

Zinc in trace quantities acts as a growth-promoting agent for plants growing under saline conditions. Studies indicate that a moderate Zn concentration of 1 mmol L^{-1} and 1% NaCl acted synergistically to yield a high final biomass in *Spartina densiflora* seedlings (Redondo-Gomez *et al.*, 2011). Iqbal and Aslam (1999) showed that Zn supplementation promoted salt tolerance in rice seedlings. The treated plants had higher tiller height, dry weight, and fresh weight under 70 mM NaCl stress. Recently, Jan *et al.* (2017) reported that Zn treatment significantly minimized oxidative stress and promoted root, shoot, and spikelet growth in salt-stressed wheat plants. The levels of photosynthetic pigments, Pro, total phenolics, and total carbohydrates were higher in the treated plants compared to the untreated seedlings under stress. While Zn counteracted the adverse effects of salinity, it also triggered high activities of SOD, CAT, and APX. The study showed that K and Zn acted synergistically to counteract salt stress in the wheat seedlings (Jan *et al.*, 2017).

Though B is phytotoxic at high concentration, trace amounts of this micronutrient is beneficial for crops. Soil application with moderate amounts of B (1.5 Kg B ha^{-1}) conferred salt tolerance in rice plants grown on saline and saline-sodic soils. The plants had higher yield and reduced Na^+ and Cl^- content in their shoots. However, a higher concentration of 6 Kg ha^{-1} severely hampered seedling growth and straw production under saline and saline-sodic conditions (Mehmood *et al.*, 2009).

2.6 Effect of micronutrients on rice

Effect of zinc and silicon on growth and yield of aromatic rice was studied in an experiment which consisted of nine treatment combinations *viz.* (T_1 - Control, T_2 - RDF 120:80:40, T_3 - RDF 120:80:40 + Two Zinc spray @ 0.5%, T_4 - RDF 120:80:40 + Two Si spray @ 0.2%, T_5 - RDF 120:80:40 + Two Si spray @ 0.3% , T_6 - NPK 150:80:40, T_7 - NPK 150:80:40 + Two Zinc spray @ 0.5%, T_8 - NPK 150:80:40 + Two Si spray @ 0.2%, T_9 - NPK 150:80:40 + Two Si spray @ 0.3%) were tested. Paddy cultivar *Navya* (IMR 002) was used as test crop. The results revealed that the application of zinc and silicon significantly influenced the growth and yield of aromatic rice. Plant height, LAI, dry weight, number of tillers, panicle length, number of grains per panicle and 1000-grains weight were recorded maximum with the application of 120:80:40 kg ha^{-1} NPK + @ 0.5% Zn spray at 30 and 45 DAT. Grain yield, straw yield and biological yield were also influenced significantly with the application of zinc and silicon and maximum grain yield was recorded with the application of 150:80:40 NPK + two Zn spray 0.5% (65.88 q ha^{-1}) followed by treatment 150:80:40 NPK + Two Si spray @ 0.3% (63.46 q ha^{-1}) and lowest in T_1 control (30.12 q ha^{-1}). Harvest index was recorded non-significant (Singh *et al.*, 2020).

Zinc (Zn) application effects (0, 10 and 20 mg Zn kg^{-1} soil and foliar application) on growth and nutrient uptake under salinity stress (3, 7 and 10 dS m^{-1}) in two rice cultivars (Tarom and Daylamani) was researched in an experiment. The results showed that Zn application under salinity stress promoted shoot and grain yield. The lowest and highest protein percent in every salinity and Zn levels belonged to Daylamani and Tarom cultivars, respectively. The results showed that the more Zn applied, the more Zn accumulated in the shoots and grain. Generally, based on the results Zn application in low and moderate salinity levels promotes the growth and yield of the rice and Daylamani cultivar showed more endurance to salinity than Tarom cultivar (Moradi and Jahanban, 2018).

Influence of foliar boron application on improvement of yield of hybrid rice was studied in a field research work. Two factors were used in the experiment, *viz.*, three rice varieties - V_1 (ACI hybrid 1), V_2 (ACI Sera) and V_3 (BRRI hybrid dhan1) and five levels of boron application - B_0 (0%; Control), B_1 (1.2% B), B_2 (1.5% B), B_3 (1.8% B) and B_4 (2.1% B). Data on different growth, yield and yield contributing parameters were recorded. Different variety and application of boron individually influenced plant height, number of leaves hill^{-1}, leaf area index, number of tillers hill^{-1}, dry weight of plant hill^{-1}, number of effective tillers hill^{-1}, number of panicles hill^{-1}, panicle length, number of filled grains panicle^{-1}, number of rachis panicle^{-1}, grain yield, straw yield, biological yield and harvest index. Interaction effect of variety and application of boron also showed significant effect on different parameters. Results revealed that the maximum number of effective tillers $hill^{-1}$ (18.60), the highest dry weight of plant $hill^{-1}$ (72.84 g), number of panicles $hill^{-1}$ (18.48), panicle length (23.16 cm), number of rachis $panicle^{-1}$ (9.78), number of filled grains $panicle^{-1}$ (166.80), grain yield (7.88 t ha^{-1}), straw yield (8.42 t ha^{-1}), biological yield (16.30 t ha^{-1}) and harvest index (48.34%) were achieved from the treatment combination of V_2B_3. So foliar boron application improves the yield of hybrid rice (Hafiz, 2017).

Response of Zn, B and Cu on the yield and quality of boro rice was evaluated in a field experiment. BRRI dhan28 was used as the test crop in this experiment. The experiment consisted of single factor with 5 different combination of fertilizers *viz.*, i. $T_1 = N_{55} + P_{35} + K_{65} + S_{18} + Zn_5 + B_4 + Cu_4$, ii. $T_2 = N_{55} + P_{35} + K_{65} + S_{18} + B_4 + Cu_4$, iii. $T_3 = N_{55} + P_{35} + K_{65} + S_{18} + Zn_5 + Cu_4$, iv. $T_4 = N_{55} + P_{35} + K_{65} + S_{18} + Zn_5 + B_4$ and v. $T_5 = N_{55} + P_{35} + K_{65} + S_{18}$ (control). The micronutrients (Zn, B and Cu) along with recommended doses of NPK had significant influence on the growth, yield and yield contributing characters of rice. The maximum weight of 1000-grains (23.82 g) was gained by T_1 and the minimum weight of 1000-grains (20.31 g) was gained by T_5. T_1 gave 17.28% more weight of 1000-grains over treatment T_5. The maximum rice yield (4.19 t ha^{-1}) was produced when the plot treated with T_1 ($N_{55} + P_{35} + K_{65} + S_{18} + Zn_5 + B_4 + Cu_4$) fertilizer package while the minimum grain yield (3.35 t ha^{-1}) was produced when the plot treated with T_5. T_1 which gave 25.08% more grain yield over T_5. Considering the above fact, fertilizer package T_1 ($N_{55} + P_{35} + K_{65} + S_{18} + Zn_5 + B_4 + Cu_4$) could be the best fertilizer management practice for optimizing the production of BRRI dhan28 during boro season (Mahmud, 2017).

Response of boro rice to foliar spray of zinc and boron was found out in an experiment. BRRI dhan29 was used as the testing variety. Treatments were, T_1 = Recommended Fertilizer (RF), T_2 = RF + Foliar spray (FS) with water at tiller initiation (TI), T_3 = RF + Foliar spray (FS) with water at flowering initiation (FI),

T_4 = Zn (0.2%) FS at TI + RF, T_5 = Zn (0.5%) FS at TI + RF, T_6 = Zn (0.8%) FS at TI + RF, T_7 = Zn (0.2%) FS at FI + RF, T_8 = Zn (0.5%) FS at FI + RF, T_9 = Zn (0.8%) FS at FI + RF, T_{10} = B (0.5%) FS at TI + RF, T_{11} = B (1.5%) FS at TI + RF, T_{12} = B (2.0%) FS at TI + RF, T_{13} = B (0.5%) FS at FI + RF, T_{14} = B (1.5%) FS at FI + RF and T_{15} = B (2.0%) FS at FI + RF. Data revealed that the tallest plant (12.39, 31.12, 44.38, 59.47 and 103.34 cm at 15, 30, 45, 60 DAT and at harvest, respectively) was obtained from T_{11} [B (1.5%) FS at TI + RF] where the shortest plant (13.18, 24.40, 33.53, 44.94 and 78.59 cm at 15, 30, 45, 60 DAT and at harvest, respectively) was found from T_1 (Recommended Fertilizer (RF)). The highest LAI (0.78, 0.85, 0.1.32, 3.00, 3.49 cm^2) at 15, 30, 45, 60 DAT and at harvest, respectively) was obtained from the treatment T_{11} [B (1.5%) FS at TI + RF] and the lowest LAI (0.74, 0.79, 1.10, 2.24, 2.58 cm^2) at 15, 30, 45, 60 DAT and at harvest, respectively) was found from T_1 (Recommended Fertilizer (RF)). The highest number of effective tillers $hill^{-1}$ (15.13), panicle length (27.86 cm) and filled grains $panicle^{-1}$ (155.52) was obtained from T_{11} [B (1.5%) FS at TI + RF] whereas the lowest was found from T_{11} (Recommended Fertilizer (RF)). The maximum days to panicle initiation, days to flowering and days to maturity (79.67, 117.67 and 152.67 days) was obtained from T_{11} [B (1.5%) FS at TI + RF] while the lowest was found from the treatment T_1 (Recommended Fertilizer (RF)). The highest grain yield, straw yield, biological yield and harvest Index (7.10 t ha^{-1}, 7.61 t ha^{-1}, 14.71 t ha^{-1} and 48.26%) was obtained from the treatment T_{11} [B (1.5%) FS at TI + RF] where the lowest was found from the treatment T_1 (Recommended Fertilizer (RF)). From the above findings, it may be concluded that among the treatment T_{11} [B (1.5%) FS at TI + RF] performed the best. So, the treatment T_{11} [B (1.5%) FS at TI + RF] showed to be the superior combination compared to other treatment combinations for rice production (Podder, 2017).

The effect of foliar application of B on yield and yield components of rice in calcareous soils with six B foliar application rates (0, 5, 10, 15, 20 and 25 mg L^{-1}) was evaluated in a research work. Boron (B) is an essential micro nutrient and its deficiency caused a reduction in final crop harvest and quality of the yield.

The results illustrated a significant effect of B foliar application on number of grains panicle^{-1}, number of filled grains panicle^{-1} and final grain yield. The highest grain yield (352 g m^{-2}) was recorded in 20 mg L^{-1} foliar application, whereas an increase in B application to 25 mg L^{-1} reduces the final grain yield significantly (313 g m^{-2}). Detrimental effects of the highest concentration of B application on yield components were also observed. The decline in the quantity and quality rice yield resulted by increasing B application might be due to the toxic effect of higher concentration of B application (Ali *et al*., 2016).

High concentration of NaCl in many cereal crops including rice, decreased zinc (Zn) availability and increased cadmium (Cd) toxicity. Zn deficiency occur when salt stress increase (Amanullah and Inamullah, 2016).

Effects of different methods of Zn application on rice growth, yield of Sakha 104 and nutrients dynamics in soil and plant was evaluated in a field experiment. The experiment included four treatments: (i) no Zn, (ii) root soaking, (iii) foliar and (iv) soil application. The Zn applied in this study was in the form of as $ZnSO_4 \cdot H_2O$. The results indicated that Zn application by different methods, significantly increased number of tillers, panicles, plant height, 1000-grains weight, filled grains% and grains yield of Sakha 104. Among the different methods of Zn application, soil application of 15 kg ha^{-1} as $ZnSO_4 \cdot H_2O$ caused the highest increase in total N percentage, total K percentage and available Zn content in both grain and straw, however, the percentage of total P decreased significantly. Zinc content in soil after harvesting was significantly affected by Zn application. Different methods of Zn tend to increase the total N and total K contents of soil but decreased P concentration significantly (Ghoneim, 2016).

Suitable rice genotypes for Zn deficient soil condition and optimum dose of Zn for sustainable production of rice was found out in an experiment. Treatments comprised of twenty rice varieties *viz.*, Chandra Hasini, Pusa Basmati, Safari-17, Swarna, Purnima, Danteshwari, Indira Sona, Indira Sugandhit Dhan-1, IR36, Bamleshwari, Samleshwari, Dubraj, Mahamaya, PKV-HMT, Shyamla, MTU-

1010, Vandana, Kranti, Madhuri and Karma Masuri and five levels of Zn *viz.*, 0.0, 10, 20, 20 kg Zn + 0.5% spray of $ZnSO_4$ and 0.5% spray of $ZnSO_4$. They reported that, application of Zn @10, 20, 20 + 0.5% foliar spray of $ZnSO_4$ and 0.5% foliar spray of $ZnSO_4$ significantly increased the straw yield of rice over control. While the application of Zn @ 10, 20 and 20 + 0.5% foliar spray of $ZnSO_4$ were also found significantly superior to 0.5% foliar spray of $ZnSO_4$ for straw yield. However, Zn @ 20 kg Zn and 20 kg Zn + 0.5% foliar spray of $ZnSO_4$ gave significantly higher straw yield than that of 10 kg Zn ha^{-1} but the levels were found on par. Application of Zn @10, 20, 20 + 0.5% foliar spray of $ZnSO_4$ and 0.5% foliar spray of $ZnSO_4$ significantly increased the grain yield of rice over control. While the application of Zn @ 10, 20 and 20 + 0.5% foliar spray of $ZnSO_4$ were also found significantly superior to 0.5% foliar spray of $ZnSO_4$ for grain yield. However, Zn @ 20 kg Zn and 20 kg Zn + 0.5% foliar spray of $ZnSO_4$ gave significantly higher grain yield than that of 10 kg Zn ha^{-1} but the levels were found on par (Kulhare *et al.,* 2016).

Effect of boron nutrition under intermittent flooding and drying condition which seemed to be sustainable nutrient management technique in rice was experimented. Rice cultivar Super Basmati was used as experimental material. The experiment was composed of two factors. First factor included different rice cultivation systems, like aerobic rice (direct seeded), flooded rice and alternate wetting and drying. In second factor, there were different boron application methods (basal and foliar). Boron fertilization treatments were: B_0 (no boron application), B_1 (basal), B_2 (2% foliar application at seedling), B_3 (2% foliar at tillering) and B_4 (2% foliar at panicle initiation). They found that, the tallest plant (113.2 cm) was recorded from B_1 and the shortest plant (94.00 cm) was recorded from B_0 treatment. The longest panicle (36.60 cm) was recorded from B_4 and the shortest panicle (18.70 cm) was recorded from B_0 treatment. The maximum number of effective tillers m^{-2} (442.80) was recorded from B_4 and the minimum number of effective tillers m^{-2} (240.90) was recorded from B_0 treatment. The maximum weight of 1000-grains (27.60 g) was recorded from B_4 and the minimum weight of 1000-grains (12.00 g) was recorded from B_0 treatment. The maximum grain yield (3599 kg ha^{-1}) was recorded from B_4 and the minimum grain yield (2119 kg ha^{-1}) was recorded from B_0 treatment (Sarwar *et al*., 2016).

Biofortification of zinc and iron on growth and yield of rice was studied in a field experiment. The experiment consisted of two factors *viz.,* soil and foliar application of zinc sulphate and ferrous sulphate. Factor-1 consisted of six soil applications *viz.,* S_1: Control (No application of $ZnSO_4$ and $FeSO_4$), S_2: $ZnSO_4$ and $FeSO_4$ application each @ 10 kg ha^{-1}, S_3: $ZnSO_4$ and $FeSO_4$ application each @ 15 kg ha^{-1}, S_4: $ZnSO_4$ and $FeSO_4$ application each @ 20 kg ha^{-1}, S_5: $ZnSO_4$ and $FeSO_4$ application each @ 25 kg ha^{-1}, S_6: $ZnSO_4$ and $FeSO_4$ application each @ 30 kg ha^{-1} and factor-2 consisted of foliar applications *viz.,* F_1: No spray of $ZnSO_4$ and $FeSO_4$, F_2: Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5%. The rice variety BPT-5204 was used as test crop. Combined soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} and foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5% recorded significantly higher yield attributing characters like productive tillers per meter row length, number of filled grains per panicle, grain yield (3739 kg ha^{-1}), straw yield (5539 kg ha^{-1}) and growth attributes like number of tillers per meter row length, LAI, SPAD value and dry matter production which were on par with that of treatment receiving soil application of $ZnSO_4$ and $FeSO_4$ each @ 20 and 30 kg ha^{-1} with foliar spray $ZnSO_4$ and $FeSO_4$ each @ 0.5% (Suresh and Salakinkop, 2016).

Application of N, P, K, S, Zn, B, and Mn separately or with different combination increased rice total above ground biomass and grain production under salt affected soils (Dash *et al.,* 2015).

Different reclamation methods on salt affected soils for crop production was studied in an experiment. The researchers concluded that under salt stress, nutrients imbalance was occurred by toxicity of Na^+ and Cl^- and deficiency of N, P, K^+, Ca^{2+}, S, Mn, and Zn^{2+} in various crops including rice (Ezeaku *et al*., 2015).

Mitigation of soil salinity in rice by application of potassium and zinc fertilizers was investigated through a field experiment. Salt-tolerant cultivar BINA dhan-10 was used as test crop. Treatments were the combination of different levels (0–200% of recommended fertilizer dose-RFD) of K and Zn. Four levels of K (0, 100, 150 and 200% of RFD) and four levels of Zn (0, 100, 150 and 200% of RFD) were employed. Potassium sulphate and zinc sulphate were used to supply K and Zn nutrients, respectively, and they were applied in two split doses, first dose during final land preparation and second dose at maximum tillering stage. All experimental plots received recommended doses of N, P and S fertilizers. Plant height, panicle length, effective tillers, grains per panicle and 1000-grain weight was significantly increased due to application of K and Zn fertilizers. Most of the yield contributing parameters showed higher values in T_{14} and T_{15} treatments compared to other treatments. Grain and straw yields of BINA dhan-10 responded significantly with the different treatment combinations. The highest grain yield (4.33 t ha^{-1}) was obtained in T_{14} ($K_{200}Zn_{150}$) and T_{15} ($K_{200}Zn_{200}$) treatments whereas the highest straw yield (5.35 t ha^{-1}) was obtained in T_{14} treatment, which was higher than all other treatments. An increase in grain yield by 22% over control was observed in both T_{14} and T_{15} treatments and straw yield showed 22% and 14% increase over the control in T_{14} and T_{15} treatments, respectively. Nutrient (NPS and Zn) uptake was higher when K and Zn were applied at higher doses. The $K^+ : Na^+$ ratio was also found higher in grain (0.42) and straw (0.44) in T_{15} treatment. Therefore, it may be concluded that application of higher doses of K and Zn fertilizers could alleviate the adverse effects of salinity in rice by increasing nutrient uptake and maintaining higher $K^+ : Na^+$ ratio (Kibria *et al.*, 2015).

Influence of foliage applied B (0.16, 0.24, 0.32, 0.40 and 0.48 M) on leaf elongation, tillering, water relations, yield and B grain enrichment of rice cultivars Super Basmati and Shaheen Basmati were evaluated. Fine grain aromatic rice cultivars Super Basmati and Shaheen Basmati were used in this study. Boron was sprayed on leaves as 0 (control), 0.16, 0.24, 0.32, 0.40 and 0.48

M B solution one week after sowing using boric acid as a source. Foliage applied B improved leaf elongation, tillering, leaf chlorophyll contents, water relations, grain yield, yield-related traits and B grain contents with simultaneous decrease in panicle sterility. However, foliage application of 0.32 M B was the most effective in this regard. An increase in leaf and grain B contents was observed with increase in B concentration in the foliar spray. There was no difference between the cultivars for grain yield; however, Shaheen Basmati had more grain weight, and grain and leaf B contents than Super Basmati. Boron foliage application (0.32 M B) proved an effective way to correct B deficiency in rice. Improvement in grain yield by B application was attributed to increase in grain size and decrease in panicle sterility (Rehman *et al.*, 2014).

Evaluation of how zinc (Zn) concentration of rice (*Oryza sativa* L.) seed may be increased and subsequent seedling growth improved by foliar Zn application was done in an experiment. Rice seeds of cultivar CNT 1 were derived from Phitsanuloke Rice Research Centre, Thailand. Eight foliar Zn treatments of 0.5% zinc sulfate ($ZnSO_4 \cdot 7H_2O$) were applied to the rice plant at different growth stages. The foliar application was applied around 10 am by evenly spraying the solution until the whole plants were wet and solution just began to drip from leaves. The rate of application was 900–1000 L ha^{-1}. The resulting seeds were germinated to evaluate effects of seed Zn on seedling growth. Foliar Zn increased paddy Zn concentration only when applied after flowering, with larger increases when applications were repeated. The largest increases of up to ten-fold were in the husk, and smaller increases in brown rice Zn. In the first few days of germination, seedlings from seeds with 42 to 67 mg Zn kg^{-1} had longer roots and coleoptiles than those from seeds with 18 mg Zn kg^{-1}, but this effect disappeared later. The benefit of high seed Zn in seedling growth is also indicated by a positive correlation between Zn concentration in germinating seeds and the combined roots and shoot dry weight ($r = 0.55$, $p < 0.05$). Zinc in rice grains can be effectively raised by foliar Zn application after flowering, with a potential benefit of this to rice eaters indicated by up to 55% increases of brown rice Zn, and agronomically in more rapid early growth and establishment (Boonchuay *et al*., 2013).

Determination of the direct and residual response of Zn on rice genotypes at the rates of 0 and 15 kg Zn ha^{-1} in low-Zn-content acidic submerged soil was done through a field experiment. The genotypes differed significantly in grain yield and its components. Single application of Zn significantly increased the growth and yield of the crop for two seasons. Based on the grain yield efficiency index, the most Zn-efficient genotypes were MR 106 and Seri Malaysia Dua. Two genotypes, MR 220 and MR 219, were moderately efficient, but MR 211 and Bahagia were classified as inefficient. Zinc (Zn) deficiency has been identified as a major cause of poor yield in rice. Flooding and submergence bring about a decline in available Zn due to pH changes and the formation of insoluble Zn compounds (Hafeez *et al*., 2013).

The effect of some nutrients in rice plant under sodic soils was studied. The researchers reported that application of N, P, K, S, Zn, B, and Mn separately or with different combination increased rice total above ground biomass and grain production under salt affected soils. The researchers concluded that under salt stress, nutrients imbalance was occurred by toxicity of Na^{+} and Cl^{-} and deficiency of N, P, K^{+}, Ca^{2+}, S, Mn, and Zn^{2+} in various crops including rice (Pandey *et al*., 2013).

The effect of different levels of boron (0.50, 1.0, 1.50 and 2.0 kg ha^{-1}) on growth, yield and ionic concentration of fine rice (Supper Basmati) directly sown on raised beds under saline-sodic soils (ECe = 5.32 dS m^{-1}, pH = 8.52 and SAR = 18.87) during 2009 and 2010 was investigated in a field experiment. The treatments under investigation were: control, 0.5, 1.0, 1.5 and 2.0 kg B ha^{-1}. The crop was harvested at maturity. Data on tillering, plant height, spike length, number of grains $spike^{-1}$, 1000-grains weight, straw and paddy yields were recorded. Na, K, Ca and B concentration in grain and straw were estimated using atomic absorption spectroscopy. Tillering, number of grains $spike^{-1}$, 1000-grains weight and paddy yield significantly ($P \leq 0.05$) increased at different levels of B. They reported that, the tallest plant (155.70 cm) was recorded in treatment receiving 1 kg B ha^{-1}. The shortest plant (147 cm) was recorded in control treatment. The longest panicle (31 cm) was produced in treatment receiving 2 kg B ha^{-1} followed by treatment receiving 1.50 kg B ha^{-1} and the shortest one (27.70 cm) was recorded from control treatment. The maximum number of tillers (28) was produced in treatment receiving 1.5 kg B ha^{-1} followed by treatment receiving 1 kg B ha^{-1} and the minimum one (19.00) was produced by control treatment. The maximum weight of 1000-grains (31.70 g) was produced in treatment receiving 2.00 kg B ha^{-1} which was 22% more than control treatment followed by treatment receiving 1.50 kg B ha^{-1} and the minimum one (29.30 g) was reported from control treatment. The maximum grain yield (5.00 t ha^{-1}) was produced in treatment receiving 2 kg B ha^{-1} which was 22% more than control treatment followed by treatment receiving 1.50 kg B ha^{-1} and the minimum grain yield (4.10 t ha^{-1}) was produced by control treatment. The maximum straw yield (17.90 t ha^{-1}) was produced in treatment receiving 1.50 kg B ha^{-1} followed by treatment receiving 2 kg B ha^{-1} and the minimum straw yield (12.20 t ha^{-1}) was produced by control treatment. Maximum number of grains $spike^{-1}$ (125) were recorded with B application @ 1 kg ha^{-1}. B concentration in grain increased with boron application. Positive correlation ($r = 0.94$) was found between B contents in grain and paddy grain yield. Economic analysis showed that maximum value cost ratio was (12.50 : 1) with the application of 1.50 kg B ha^{-1} (Hyder *et al.*, 2012).

Influence of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice was studied in a glass house experiment. Four rates of zinc were applied to create different levels of soil Zn. These zinc rates of 0. 2.5, 5.0, 7.5 mg Zn kg^{-1} were applied using zinc sulfate. Recommended dose of 150 N kg ha^{-1}, 50 P_2O_5 kg ha^{-1} and 50 KCl kg ha^{-1} applied through 1.63 g pot^{-1} urea, 1.56 g pot^{-1} superphosphate and 0.4 g pot^{-1} muriate of potash. The tested rice variety used in this experiment was ADT 43. The results revealed that rice responded significantly to graded dose of zinc applied. The highest grain (37.53 g pot^{-1}) and straw yield (48.54 g pot^{-1}) was noticed at 5 mg Zn kg^{-1} which was about 100% and 86% greater than control (no zinc) respectively. Similar effect was noticed on DMP. The highest zinc concentration and uptake in grain and straw and DTPA-Zn at all stages was noticed at 7.5 mg Zn kg^{-1}. The linear regression analysis showed grain zinc concentration and grain Zn uptake caused 89.64% and 89.01% variation in rice yield. Similarly, the linear regression analysis of DTPA-Zn caused 98.31%, 96.34% and 93.12% variation in yield of rice at tillering, panicle initiation and harvest stages, respectively. The agronomic, physiological and agro-physiological apparent recovery and utilization efficiencies was highest at lower level of zinc application and decreased with Zn doses (Muthukumararaja and Sriramachandrasekharan, 2012).

Potential of boron nutripriming in improving the germination and early seedling growth of rice was explored in a laboratory study. Seeds of fine grain aromatic rice cultivar Super Basmati were primed in aerated B solution (0.001, 0.01, 0.1 and 0.5% w/v) while untreated dry seeds were taken as control. Seed priming in 0.001 and 0.1% B solutions improved the time to 50% germination, germination energy, final germination percentage, mean germination time and germination index. Beyond this concentration either there was no effect or an adverse effect on rice seeds. In the cases of radicle length, plumule length and secondary roots priming more diluted B solution, i.e., 0.001% proved better than rest of the treatments as suppression in these three traits was observed by other B treatments than control. Seed priming in relatively concentrated B solution, i.e., 0.5% completely suppressed the germination and growth (Farooq *et al*., 2011).

Evaluation of the effect of different methods and timing of zinc application on growth and yield of rice was done in a field experiment. The experiment comprised of eight treatments *viz.*, control, rice nursery seedlings root dipping in 0.5% Zn solution, $ZnSO_4$ application at the rate of 25 kg ha^{-1} as basal dose, foliar application of 0.5% Zn solution at 15, 30, 45, 60 and 75 days after transplanting. The results of the experiment revealed that, the tallest plant (104.5 cm) was recorded in treatment Zn_1 (Nursery root dipping at the rate of 0.5% Zn solution) while minimum plant height (103.1 cm) was recorded in treatment Zn_5 when foliar application was done 45 days after transplanting. Foliar application 15 days after transplanting (DAT) produced panicle length of 26.64 cm as compared with control which gave 24.15 cm panicle length. In control, 8.27% lesser number of total tillers m^{-2} were produced as compared to basal application of zinc at the rate of 25 kg ha^{-1} 21% $ZnSO_4$. The maximum effective tillers m^{-2} (249.80) was recorded from basal application @ 25 kg ha^{-1} 21% $ZnSO_4$ whereas the minimum one (237.02) was recorded from no zinc application plot. The maximum weight of 1000-grains (21.00 g) was recorded from foliar application at 15 DAT @ 0.5% Zn solution whereas the minimum one (18.52 g) was recorded from no zinc application plot. The maximum grain yield (5.21 t ha^{-1}) was recorded from basal application @ 25 kg ha^{-1} 21% $ZnSO_4$ whereas the minimum grain yield (4.17 t ha^{-1}) was recorded from foliar application at 75 DAT @ 0.5% Zn solution. The maximum biological yield (11.87 t ha^{-1}) was recorded from foliar application at 15 DAT @ 0.5% Zn solution whereas the minimum grain yield (10.56 t ha^{-1}) was recorded from foliar application at 60 DAT @ 0.5% Zn solution (Mustafa *et al.*, 2011).

Effect of Zn^{+2}, Fe^{+2} and Mn^{+2} as single or combined application in soil to rice (Sakha 101 as moderately salt tolerant rice variety) growth and yield was studied in field trials. The treatments included Zn^{+2}, Mn^{+2}, Fe^{+2} application as soil single treatments or Zn + Mn, Zn + Fe, Mn + Fe and Zn +Mn + Fe as a combined application through soil as well as a comparative treatment of commercial compound (14% Mn + 12% Fe +16% Zn) was applied twice at 20 and 45 days after transplanting (DAT) as foliar spray. They found that, the tallest plant (97.00 cm) was attained by Zn^{+2} + Fe^{+2} + Mn^{+2} combined treatment and the shortest plant (86.87 cm) was attained by control treatment (no micronutrients). The maximum panicle length (21.30 cm) was attained by foliar (comparative treatment) and the shortest plant (19.35 cm) was attained by control treatment (no micronutrients). The maximum number of effective tillers $hill^{-1}$ (17.00) was attained by Zn^{+2} + Fe^{+2} + Mn^{+2} combined treatments and the minimum one (15.00) was attained by control treatment (no micronutrients). The maximum weight of 1000-grains (28.50 g) was attained by foliar application (comparative treatment) and the minimum weight of 1000-grains (26.35 g) was attained by control treatment (no micronutrients). The highest grain yield (2.27 t fed^{-1}) was attained by Zn^{+2} + Fe^{+2} + Mn^{+2} combined treatment and the lowest grain yield (1.77 t fed^{-1}) was attained by control treatment (no micronutrients). The highest straw yield (3.31 t fed^{-1}) was attained by Zn^{+2} + Fe^{+2} + Mn^{+2} combined treatment and the lowest straw yield (2.92 t fed^{-1}) was attained by control treatment (no micronutrients). The highest harvest index (42.00%) was attained by foliar (comparative treatment) and the lowest harvest index (37.80%) was attained by control treatment (no micronutrients) (Zayed *et al.,* 2011).

By-product of sugarcane (press mud), green manure, poultry manure, and *Sesbania* as cover crop can be used for amendment of soil to reduce the effect of salt stress which is source of macro and micro nutrients specially Zn and S in rice crop (Ismail, 2009).

Nutritional functions of boron were investigated in improving rice growth and yield, both in solution and soil culture environments. Three rice cultivars [viz., KS-282 (salt-tolerant), BG-402-4 (mixed behaviour) and IR-28 (salt-sensitive)] of differential salinity tolerant were used to investigate the ameliorative nutritional aspects of boron. Boron was applied @ 25, 50, 100, 200, 400 and 800 mg B mL^{-1} in the presence (80 mol m^{-3}) and absence (0 mol m^{-3}) of NaCl salinity whereas in solution culture, B was applied @ 1.5, 3.0 and 6.0 kg ha^{-1} artificially to prepare saline (ECe 9.0 dS m^{-1}, SAR 5.46, pHs 7.8), and saline-sodic soils (ECe 9.0 dS m^{-1}, SAR 28.2, pHs 8.2). Application of B improved all growth parameters i.e., tillering capacity, shoot and root length and shoot and root weight because of external B application @ 200–400 mg mL^{-1} in solution culture in the presence and absence of NaCl salinity. In shoot Na^+ and Cl^- decreased; whereas K^+ concentration and $K^+ : Na^+$ ratio improved because of B supplied to saline medium. The ameliorative effect on paddy and straw yield and paddy :

straw ratio was recorded at all external B supplied as compared to control. The highest improvement was recorded at 1.50 kg B ha^{-1} in the saline and saline sodic soils. Nevertheless, the highest B application @ 6 kg B ha^{-1} had shown an adverse effect on paddy and straw production in saline sodic soils in all the three cultivars as compared with all other B rates and control. The beneficial effect of B was due to reduced shoot Na^+ and Cl^- concentration and better ratio of K^+ and Na^+ in shoot. Seed setting was improved in all the three cultivars because of external B supply to saline and saline-sodic soils (Mehmood *et al.*, 2009).

Evaluation of the effects of Zn nutrition and salinity stress and their interaction on agronomical traits, chlorophyll and proline content of rice plant was done in a greenhouse experiment. Eight local and improved low land genotypes of rice plant were used in this experiment. Four genotypes were provided from IRRI (Philippines). Three Zn-efficient genotypes (Pokkali, IR 9884 and IR9764) and the other Zn-inefficient (IR26) used as control. Four Iranian varieties, Shafagh (improved variety, Zn-efficient) and Kados (Improved variety, Zn-inefficient), Domsiah and Hashemi (local variety, Zn-inefficient) genotypes were obtained from Rice Research Institute of Iran. Salinity treatments (0 and 6 dS m^{-1}) were applied at the tillering stage till maturity. The rice genotypes were grown at 0, 10 and 20 mg Zn kg^{-1}. Panicle number, panicle length, plant height, total number of filled grains and 100 grain weight recorded at the end of plant growth. Results showed that interaction between Zn × salinity effects on filled grains, 100 grain weight and chlorophyll content were widely varied in rice plant genotypes. Only 100 grain weight was significantly differed at Zn × salinity × genotype interaction levels. Free proline content was significantly lower in Zn-efficient genotypes (Shafagh, Pokkali, IR9764 and IR9884) in comparison with Zn-inefficient genotypes (Hashemi, Domsiah, Kados and IR26). It seemed that under salinity stress, the higher content of free proline could be considered as an injury indicator in rice plant. It could be concluded that Zn-efficient rice genotypes tolerated salinity better than the Zn-inefficient genotypes (Jamalomidi *et al.*, 2006).

Comparative effect of Zn levels applied by different methods i.e. (i) nursery root dipping in 1.0% $ZnSO_4$ for five minutes before transplanting, (ii) 0.20% $ZnSO_4$ solution spray 10 days after transplanting and (iii) 10 kg Zn ha^{-1} by field broad cast method was evaluated in a field experiment. Thirty days old nursery seedlings of rice variety IRRI-6 was transplanted in standing water. A significant increase in Zn content of rice leaf before and after flowering and a significant decrease in P content of straw and paddy and starch content of paddy was recorded for all the methods. N, K and Zn of paddy and straw and Zn contents of roots increased significantly with the application of zinc irrespective of the methods over control. Soil application of Zn was rated superior because it gave significantly higher content of N in rice paddy (Ali *et al*., 2003).

2.7 Genetic variation of rice under salinity stress

Agronomic status and adaptability of four modern rice varieties in comparison with the popular mega variety BRRI dhan28 was tested in an experiment at two farmer's fields of Batiaghata and Dumuria sub-district under Khulna district of Bangladesh. The varieties were BRRI dhan67, BRRI dhan81, BRRI dhan84 and BRRI dhan86. BRRI dhan28 was chosen as a control due to its wide acceptability among the farmers. The soil of the studied area was moderately alkaline and medium to moderately saline. In Batiaghata and Dumuria field, initial soil EC was 3.19 and 3.29 dS m^{-1}, respectively and it was 4.7 and 4.8 dS m^{-1}, accordingly at maturity stage. It was observed that germination rate, plant height, effective tiller number were significantly higher in BRRI dhan67 than the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for both fields. All the yield components spikelets per panicle, filled grain and 1000-grains weight were also significantly higher in BRRI dhan67 in compared to the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for both fields as well. The highest grain yield was observed in BRRI dhan67 in both plots (7.89 t ha^{-1} and 7.29 t ha^{-1}) and showed significant differences among all other varieties ($p \leq 0.05$). Harvest Index of BRRI dhan67 (51.02 ± 4.2, 57.84 ± 8.6) % indicated that this variety is the best yielder among the varieties. Considering overall performances and facts, BRRI dhan67 showed better agronomic performance and adaptation than the other modern varieties in compare with popular mega BRRI dhan28 (Salam *et al.,* 2019).

Performance of newly released high yielding rice variety was evaluated in a farmers' participatory block demonstration under both saline and non-saline area. Salt tolerant BRRI dhan67 was compared to BINA dhan-10 in the saline environment and premium quality BRRI dhan63 was compared to popular variety BRRI dhan28 in the non-saline area in Boro-Fallow-T. Aman cropping system. Results revealed that BRRI dhan67 gave higher yield, gross margin and gross return than BINA dhan-10 in the saline area whereas in the non-saline area the performance of BRRI dhan63 was better than existing popular variety BRRI dhan28. Farmers' also preferred BRRI dhan67 and BRRI dhan63 to BINA dhan-10 and BRRI dhan28, respectively. In a nutshell, it can be said that BRRI dhan67 can be grown successfully in saline area while BRRI dhan63 in non-saline condition of Satkhira region (Shirazy *et al.,* 2019).

Determination of the effect of different level of salinity on two rice varieties viz. BRRI dhan28 and BRRI dhan47 during boro season (2017–2018) and finding out the comparative performance of two varieties under salinity was performed in a pot experiment. Mixture of fresh water and marine water was used as salinity treatments. Four salinity treatments were used in this experiment viz. control S_0 (only fresh water), Quarter strength marine water S_1 (Three-part fresh water and one-part marine water), Half strength marine water S_2 (half fresh water and half marine water), Full strength marine water S_3 (only marine water). These mixtures were used for irrigation purpose throughout the life cycle. Salt stress significantly reduced plant height, number of tillers hill^{-1}, leaf relative water content, number of effective tillers hill^{-1}, panicle length, number of filled grains panicle^{-1}, 1000-grains weight, grain yield, straw yield and biological yield but increased the number of non-effective tiller hill^{-1} and unfilled grain panicle^{-1}. Leaf relative water content (RWC) also decreased due to salinity. With rise in salinity level adverse effect of salinity was more clearly visible. Different growth stages showed different sensitivity to salinity. In fact, the primitive growth stages, that is, tillering and panicle initiation showed more sensitivity to salinity than final growth stages (panicle emergence and ripening). Therefore, irrigation with saline water at the early growth stages has more negative effect on yield and its components. Between the two varieties used in this experiment BRRI dhan47 performed better than BRRI dhan28 under salinity stress condition (Islam, 2018).

Clarification of the growth and yield response of two rice cultivars, BR55 and BR43 under salt stress was done in an experiment. Six different concentrations of NaCl *viz*. 50, 100, 150, 200, 250 and 300 mM and distilled water (control) were applied on the rice cultivars which were grown under pot culture condition. Growth parameters like plant height, tiller number, leaf number and leaf area were negatively affected by salinity in both cultivars. Salt stress caused a significant reduction in yield in both cultivars of rice. Growth reduction was higher in BR43 than in BR55. The reduction in yield and yield parameters were found to be lower in BR55 than those in BR43. The results obtained in the present study suggest that BR55 showed higher salt tolerance than in BR43 (Khanam *et al.*, 2018).

Different growth and yield contributing parameters of five modern varieties of rice were compared with two local Aman rice cultivars at the farmer's field. Modern varieties showed superiority in most of the characters over local cultivars. Five modern varieties viz. Binadhan-7, Binadhan-13, Binadhan-16, Binadhan-17, BRRI dhan71 and two local cultivars viz. Chakka Panja and Binni dhan were used. Results revealed that, the highest plant height (131 cm), days to maturity (145) and longest panicle length (25.49 cm) were found with Binadhan-13; earliest flowering and days to maturity (72 days and 100 days) were recorded in Binadhan-16, total number of tillers per hill (19.80) and thousand seed weight (26.03 g) were also found to be maximum by Binadhan-16; percent sterility of spikelets was the highest in Chakka Panja cultivar (33.28%); Binni dhan cultivar produced the highest biological yield (24.14 t ha^{-1}) and BRRI dhan71 gave the longest root area (21.43 cm^2). In terms of grain yield, highest was obtained from BRRI dhan71 (6.03 t ha^{-1}) followed by Binadhan-17 (5.05 t ha^{-1}); Binadhan-16 (4.51 t ha^{-1}); Binadhan-7; Binni dhan (4.44 t ha^{-1}); Chakka Panja (4.07 t ha^{-1}) and the lowest was recorded in Binadhan-13 (2.77 t ha^{-1}). Though local cultivars are low yielded and of more duration but they are cultivated widely in the hilly areas for their quality and taste. To increase the cropping intensity and yield; the short duration high yielding Aman rice varieties may be a better option for the farmers (Chowhan *et al.*, 2017).

Morphophysiological and biochemical responses of two popular cultivars of rice (BRRI dhan29 and BRRI dhan48 from *indica* and Koshihikari from *japonica*) under salinity and drought stress either alone or in combination at early vegetative stage were investigated in a research study. Eighteen-days-old seedlings were subjected to salinity (150 mM NaCl), drought (PEG-6000, 15%) and combined salinity and drought (150 mM NaCl + PEG-6000, 15%) *in vitro* for 72 h. Salinity and drought alone and in combination increased mortality rate, decreased seedlings height, reduced biomass, abated water status and lowered photosynthetic pigments content in all three cultivars but the worst effects were observed in BRRI dhan29 and Koshihikari compared to BRRI dhan48. Moreover, under stress conditions compared with control a substantial increase was seen in the rate of electrolyte leakage (EL), elevated levels of H_2O_2, lipoxygenase (LOX) activity, malondialdehyde (MDA) and methylglyoxal (MG) content which indicated an enhancement of lipid peroxidation in rice cultivars. The reduction of reduced ascorbate (AsA), lower AsA : DHA and GSH : GSSG ratio under salinity stress and combined stress indicate the disruption of redox balance in the cell. But under stress conditions compared with other varieties BRRI dhan48 showed lower Na^+:K^+ ratio, elevated proline (Pro.) content, higher AsA and reduced glutathione (GSH) activity, higher AsA : DHA and GSH : GSSG ratio and enhanced activities of MDHAR, DHAR, GPX and glyoxalase system. The results suggested that higher tolerant capacity of BRRI dhan48 against salinity, drought and combined stress is related to lower Na^+ : K^+ ratio, enhanced Pro content and better performance of glyoxalase system and antioxidant defence for scavenging reactive oxygen species (ROS) and these results may provide insight into possible responses associated with single or combined stress of salinity and drought in rice cultivars (Hossen, 2017).

Performances of short growing photo-insensitive rice varieties to evade cyclonic hazard in the coastal region during Aman season were studied at a farmer's field. The varieties included in the study were BRRI dhan62, BINA dhan7, BINA dhan8, BINA dhan10, BINA dhan11, and Maloti (local). Variety Maloti produced the tallest plant (126 cm) and BRRI dhan62 produced shortest plant (93 cm). Variety BINA dhan7 and BINA dhan11 produced the highest LAI (3.90) and total dry matter (1165 g plant^{-1}), respectively. Yield of different rice varieties varied significantly. Variety BINA dhan11 gave the highest yield (5.033 t ha^{-1}) which was statistically at par with that of BINA dhan7 (5.00 t ha^{-1}) and BINA dhan8 (4.50 t ha^{-1}), BINA dhan10 (3.933t ha^{-1}), BRRI dhan62 (4.167 t ha^{-1}). The highest grain yields of these varieties were obtained from the highest number of bearing tillers m^{-2}. The lowest grain yield (3.50 t ha^{-1}) and straw yield (4.840 t ha^{-1}) were found in Maloti. The shortest period for first flowering (66 days) was observed in BRRI dhan62. Among the varieties, the longest maturity stage (139 days) was observed in local *var*. Maloti. While the shortest period was observed in BRRI dhan62 (94.5 days). So, the experiment concluded that BINA dhan11 was the highest performing short duration variety followed by BINA dhan7, while BRRI dhan62 and, BINAdhan8, BINAdhan10 performed better among the short duration varieties respectively during Aman season to evade cyclonic effect and for cultivating boro rice in Bakergonj Upazilla of Barisal district (Isa *et al.*, 2015).

Effect of salinity on two rice varieties BINA dhan 10 and BRRI dhan47 was observed in a pot experiment at the net-house during Boro rice cropping season (December 2012 to June 2013). Five salinity levels viz. 0, 4, 8, 12 and 16 dS m^{-1}were imposed. The results on the effect of morphological characters indicated that plant height, total tillers, effective tiller, number of non-effective tiller, root dry weight, shoot dry weight, number of filled grains, number of unfilled grains, panicle length and grain yield were influenced by the varieties. The tallest plant was found in cultivar BRRI dhan47. BINA dhan 10 achieved maximum number of total tillers, root dry weight (RDW), effective tillers hill^{-1}, panicle length, number of filled grains panicle^{-1}. Among the two varieties, the highest grain yield (3.40 g hill^{-1}) was found in cultivar BINA dhan 10 and the lowest yield (2.66 g hill^{-1}) was recorded in BRRI dhan47. Among different salinity levels, the highest growth and yield contributing characters found at 0 dS m^{-1}. The maximum number of total tillers hill^{-1}, effective tillers hill^{-1}, RDW and SDW, panicle length and number of filled grains panicle^{-1} were found at 0 dS m^{-1}. The highest grain yield (6.09 g hill^{-1}) was also recorded at control treatment. Among the combined effects of varieties and salinity levels, highest grain yield (6.86 g hill^{-1}) was obtained from BINA dhan 10 at 0 dS m^{-1} and at 4, 8, 12 dS m^{-1} salinity levels BINA dhan 10 showed better result than BRRI dhan47. Among the two varieties, K content was the highest in BINA dhan 10 than BRRI dhan47. In both varieties K content decreased significantly with the increasing salinity level. Na content was higher in BRRI dhan47 than BINA dhan 10. In both varieties it increased significantly with the increasing salinity level (Islam, 2012).

Extent of variation in salinity tolerance of rice (*Oryza sativa* L.) genotypes was evaluated in two experiments, one at laboratory and the another one at the Vinyl-house of the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur from March–December, 2010. In the first experiment, one hundred genotypes and two check cultivars (Pokkali as tolerant and IR29 as susceptible) were exposed to salt solutions of electrical conductivity (EC) of 10, 15, and 20 dS m^{-1} (5:1 molar concentration of NaCl and $CaC1_2$ solution) at germination and early seedling stage. Based on the visual salt injury symptoms at 15 dS m^{-1}, 13 genotypes were found fairly tolerant to salinity. However, among the 13 genotypes, only Patnai23 showed higher germination index (92.7) and relative seedling dry weight (90.88%) than the check salt tolerant Pokkali (89.60 and 88.08%) at 15 dS m^{-1}. Performance of Awned-1, Nonasail and Soloi was also well at this level. The genotypes Patnai 23, Awned-1, Nonasail and Soloi showed the best performance under saline condition. Based on the first experiment, relatively salt-tolerant eleven genotypes were used in the second experiment. Among the eleven genotypes, finally three genotypes (Patnai 23, Chapali and Soloi) were considered as moderately salt tolerant, on the basis of their yield and yield contributing characteristics, such as plant height reduction, total tiller reduction, effective tiller reduction, reduction of fertile grain per panicle, grain yield and relative grain yield (Faurqe, 2011).

Salinity effect on growth and yield of rice during the Aman season (June–December) was studied in a pot culture experiment. Four rice cultivars namely Sadamota, BRRI dhan40, Heera and Lalmota and five salinity levels (0, 3, 6, 9 and 12 dS m^{-1}) were imposed in the experiment. During the experiment, plant height, relative root length, relative root dry weight, relative shoot dry weight, relative total dry matter, effective tiller $hill^{-1}$, non-effective tiller $hill^{-1}$, panicle length, number of filled and unfilled grains $panicle^{-1}$, thousand grains weight and yield $hill^{-1}$ of the rice cultivars were measured. The results indicated that all the parameters have significant varietal differences among them. The tallest plants were found in Sadamota and Lalmota cultivars while shortest plants were obtained from Heera. But relative shoot dry weight and relative total dry matter were highest in Heera as it contained maximum effective and non-effective tillers $hill^{-1}$. Panicle length, number of filled grains $panicle^{-1,}$ thousand grain weight and grain yield $hill^{-1}$ were the maximum in Heera and the lowest in BRRI dhan40 and Lalmota due to the mean effect of five salinity levels. Plant height was the highest at control salinity treatment and lowest in the maximum salinity level (12 dS m^{-1}) for every cultivar. Similar results were observed in case of relative root dry weight, relative shoot dry weight, relative total dry matter, number of effective tillers $hill^{-1}$, panicle length and number of filled grains $panicle^{-1}$ for each of the cultivars. All the parameters decreased with increasing salinity but this decreasing tendency was slower in Heera than other cultivars. On the other hand, number of non-effective tillers $hill^{-1}$ and unfilled grain $panicle^{-1}$ increased with the increasing level of salinity and the highest values were obtained from maximum salinity level in BRRI dhan40. At the highest (12 dS m^{-1}) level of salinity, significantly better performance for thousand grain weight and grain yield $hill^{-1}$ was given by Heera while BRRI dhan40 was the most badly affected one by salinity (Hossain, 2011).

Morphology and mineral content in shoots of some rice cultivar under salinity effects in a pot-culture was studied. The experiment was completed using five varieties (Jatabalam, Chapsal, Kolar-mocha, BINA dhan 8 and BRRI dhan41) and five salinity levels (0, 3, 6, 9 and 12 dS m^{-1}). The plant height, total tiller number, shoot dry weight, root dry weight, effective tiller, grain weight was the highest in genotypes BRRI dhan41 but Kolar-mocha showed the lowest performance under different salinity levels. The highest concentration of Na^+, Ca^{2+} and Mg^{2+} was in Kolar-mocha and it was the lowest in BRRI dhan41. The shoot of BRRI dhan41 contained the highest concentration of K^+. Conversely, Kolar-mocha contained the lowest amount of K^+. The plant height, total tiller number, shoot dry weight, root dry weight, effective tiller, filled grain, grain weight were the highest in 0 dS m^{-1} level of salinity. The highest K content in shoot (1.64%) was recorded in 0 dS m^{-1}. The highest Na content in shoot (1.584%) was recorded in 12 dS m^{-1} level of salinity. The Ca content recorded in shoot was the highest (1.07%) in 6 dS m^{-1}. The lowest Mg (0.35%) content was in the shoot in 0 dS m^{-1}. The maximum panicle length and filled grain $panicle^{-1}$ was recorded in BRRI dhan41 at 0 dS m^{-1} level of salinity. The minimum number of unfilled grain $panicle^{-1}$ was found in BRRI dhan41 at 0 dS m^{-1}. The highest grain yield $hill^{-1}$ (5.00 g) was found in BRRI dhan41 at 0 dS m^{-1} salinity level. The lowest Na content (0.78%), Ca content (0.75%) and Mg content (0.33%) in shoot was found in the cultivar BRRI dhan41 at the 0 dS m^{-1} salinity level. Considering the above results, cultivar BRRI dhan41 and BINA dhan 8 were salt tolerant, Chapsal as moderately tolerant and Kolar-mocha and Jatabalam as susceptible cultivar (Sutradhar, 2011).

Performance on the variability of rice yield under water and soil salinity risks in farmers' fields in northeast Thailand was focused in a field research work. A rice plot was monitored in 24, 16 and 11 farmers' fields during the rice seasons 2005, 2006 and 2007, respectively. The results emphasized that few plots were continuously submerged during the 2005 season, when rainfall was low. Drought significantly affected the rice yield, yield components and the internal efficiency (IE) of the absorbed nutrients, while slight soil salinity had the only significant effect of increasing the IE of potassium (IEK). In the very rainy 2006 and 2007 seasons, most fields were continuously submerged, and in contrast to 2005, the slight soil salinity that was recorded had significant effects not only on IEK, but also on rice yield, spikelet sterility and 1000-grains weight. The yield decrease due to drought was about 87% and that due to salinity was 20%. When neither salinity nor water were limiting, the soil nutrient supply was high enough to achieve about 80% of the maximum yield reported in the literature for the rice cultivar in this area. As both drought and salinity risks are hardly avoided by the current farmers' management, they should be considered the technical recommendations which are formulated to farmers (Dauphina *et al.,* 2010).

Salinity effect on growth and yield of rice during the Boro season (December–June) was studied in a pot culture experiment. Four rice varieties namely Pokkali, BR 28, BRRI dhan29 and IR 29 and five salinity levels (0, 3, 6, 9 and 12 dS m^{-1}) were imposed in the experiment. Plant height, root length, root dry weight, shoot dry weight, effective tiller $hill^{-1}$. non-effective tillers $hill^{-1}$, panicle length, number of filled and unfilled grains $panicle^{-1}$, thousand grains weight, yield $hill^{-1}$ of the rice varieties were measured as parameters. The results indicated that significant varietal differences were found in panicle length, effective tiller $hill^{-1}$, number of filled and unfilled grains $panicle^{-1}$, thousand grains weight and yield $hill^{-1}$. Plant height was the highest at control salinity treatment and the lowest in the maximum salinity level (12 dS m^{-1}) for every cultivar. Similar results were observed in case of root length, root dry weight and shoot dry weight. The total dry matter content also negatively affected by salinity where 12 dS m^{-1} showed the lowest values for each of the cultivars. Number of effective tillers hill^{-1}, panicle length and number of filled grains panicle^{-1} decreased with increasing salinity. On the other hand, number of non-effective tiller hill^{-1} increased with the increasing level of salinity and the highest values were obtained from maximum salinity level. Thousand grains weight and grain yield hill^{-1} showed negative relationship with salinity and also showed varietal difference significantly (Islam, 2010).

The effects of salinity on yield and yield components of rice genotypes were studied. It was found that the yield per plant, chlorophyll concentrations, fertility percentage, and number of productive tillers, panicle length and number of primary branches per particle of all the genotypes were reduced by salinity. However, genotypes viz. Jhorna-349 × Basmati-370, NR-1, DM-59418, DM-63275, DM-64198 and DM-38-88 showed better salinity tolerance than others (Ali *et al.,* 2009).

Different levels of salinity effect on the germination, growth and yield of four irrigated rice (*Oryza sativa* L.) cultivars were verified. The 4 different rice varieties used in the experiment were - BR11, BRRI dhan41, BRRI dhan44 and BRRI dhan46. The experiment was performed with 6 NaCl concentrations *viz.* 0, 30, 60, 90, 120 and 150 mM. It was observed that seed germination, plant height, tiller number and leaf area index are negatively influenced by different salinity levels in all the rice varieties. All the yield components that is number of panicles, panicle length, spikelets per panicle, filled grain and grain weight also significantly decrease with the increased salinity stress. An increase of NaCl concentration up to 150 mM decreased 36–50% of the grain yield of all the four rice varieties. Among the varieties BRRI dhan41 showed better performance at salinity stress up to a certain level (Hasanuzzaman *et al.,* 2009).

Assessment of the salt tolerance of 4 commercial varieties and 17 breeding lines of Basmati rice (*Oryza sativa* L.) at early growth stage and at maturity in field plots artificially salinized with NaCl and $CaCl_2$ (1:1 by weight) was conducted. The average electrical conductivity (EC) of soil was 1.2, 5.2 and 10.5 dS m^{-1}. Forty-five days after sowing (20 days in saline or control conditions), shoot dry weights and sodium (Na) and potassium (K) contents of shoot were determined. At maturity, plant height, number of tillers per plant, panicle length, number of grains per panicle, 1000-grains weight, grain sterility, shoot dry weight, grain straw ratio and grain yield per plant were measured. There was significant variation among genotypes for all the characters studied. On an average, plant height, number of tillers per plant, panicle length, number of grains per panicle, shoot dry weight, grain straw ratio, grain yield per plant, K content of shoot and K : Na ratio were reduced linearly while grain sterility and Na content of shoot were increased with increasing soil salinity. With increased salinity, reduced number of grains per panicle was mainly found responsible for reduction in grain yield. Generally, genotypes having ability to exclude Na from shoot were found salt tolerant in respect of grain yield and *vice versa.* Na contents of shoot and shoot dry weight 45 days after sowing (DAS) showed significant correlations with grain yield. It is suggested that selection for salinity tolerance in rice can be carried out at an early stage of growth (Muhammad *et al.*, 2009).

Screening of the salinity tolerant varieties among the five advanced mutant rice (*Oryza sativa* L.) lines as RM-250-133, PNR-381, Y-1281, PNR-166, RD-2586 and one high yielding Boro rice, Iratom-24 was completed in an experiment in earthen-pots. The plants were grown in pot soils under different salinity levels such as control (0.42 dS m^{-1}), 6 dS m^{-1}, 9 dS m^{-1} and 12 dS m^{-1} to assess their performance on morpho-physiological parameters, dry matter production and its partitioning, yield attributes, Na^+, K^+ and Ca^+ content in leaves. The morpho-physiological parameters like plant height, number of tillers plant^{-1}, number of leaves plant^{-1}, leaf area plant^{-1} decreased with the increasing salinity levels. Varietal differences were also observed in these parameters. The line PNR-166 and RD-2586 showed the lesser decrease in those parameters at elevated salinity levels. In dry matter production and its partitioning ability into different plant parts i.e. root, stem, leaf and total dry matter (TDM) plant^{-1} revealed gradual decrease with the increasing salinity levels. The line PNR-381 though produced the highest TDM in control condition but the line RD-2586 and PNR-166 produced higher TDM at 12 dS m^{-1} than the PNR-381. The data on the yield component such as number of panicles plant^{-1}, length of panicle, number of filled grains panicle^{-1}, grain yield plant^{-1}, 1000-grains weight, harvest index (%) resulted in varietal variations in response to different salinity levels. The mutant line RD-2586 possessed the highest and PNR-166 showed the second highest number of panicles^{-1}, number of filled grains panicle^{-1}, 1000-grains weight and correspondingly the grain yield plant^{-1}. The variety Iratom-24 possessed the medium yield. The K^+ and Ca^{++} content of leaves was found to decrease and Na^+ was found to increase with increasing salinity level (Hossain, 2006).

Evaluation of the effective salt-tolerance defence mechanisms in aromatic rice varieties was investigated. Pathumthani 1 (PT1), Jasmine (KDML105). and Homjan (HJ) aromatic rice varieties were chosen as plant materials. Rice seedlings photo-autotrophically grown *in-vitro* were treated with 0, 85, 171, 256, 342 and 427 mM NaCl in the media. Data, including sodium ion (Na^+) and potassium ion (K^+) accumulation, osmolarity, chlorophyll pigment concentration and the fresh and dry weights of seedlings were collected after salt-treatment for 5 days. Na^+ in salt-stressed seedlings gradually accumulated, while K^+ decreased, especially *in* the 342–427 mM NaCl salt treatments. The Na^+ accumulation in both salt-stressed root and leaf tissues was positively related to osmolarity, leading to chlorophyll degradation. In the case of the different rice varieties, the results showed that the HJ variety was identified as being salt-tolerant, maintaining root and shoot osmolarities as well as pigment stabilization when exposed to salt stress or Na^+ enrichment in the cells. On the other hand, PT1 and KDML105 varieties were classified as salt-sensitive. determined by chlorophyll degradation using Hierarchical cluster analysis. In conclusion, the HJ-salt tolerant variety should be further utilized as a parental line or genetic resource in breeding programs because of the osmoregulation defensive response to salt-stress (Cha-um *et al.*, 2005).

Plant height of four rice genotypes was seriously decreased by salinity level in salt affected soils of the farmers' fields (Saleque *et al.,* 2005).

Performance of three advanced lines of transplanting Aman rice viz. PNDB-100, PR-26305-M-2 and PNR-166 was assessed on morphological parameters, Na^+, K^+ and Ca^{++} absorption in leaves, yield attributes and yield under different salinity levels in a pot experiment. The salinity levels were control (0.27 dS m^{-1}), 6 dS m^{-1} and 8 dS m^{-1}. Plant height, number of tillers, leaves and leaf area $hill^{-1}$, stem, leaf and total dry matter (TDM) $hill^{-1}$, length of panicles, number of filled grains and number of unfilled grains $panicle^{-1}$, 1000-grain weight, grain $yield^{-1}$, K^+ and Ca^{++} content in leaves were gradually decreased with the increase level of salinity compared to control. On the other hand, root dry weight $hill^{-1}$, unfilled grains $panicle^{-1}$ and Na^+ content in leaves were increased with increasing salinity level. The advanced lines PNDB-100 and PNR-166 contained lower Na^+ content in leaves and produced grain yield up to 8 dS m^{-1} soil salinity. Among the three advanced lines, PNR-166 showed the best performance in most of the above parameters and showed tolerance to salinity. PNDB-100 was intermediate and PR-26305-M-2 showed less tolerance to salinity (Islam, 2004).

The effect of different levels of salinity on some yield attributes of rice was studied with a variety of rice BR11 at a greenhouse laboratory. The experiment was conducted with different salinity level e.g., 0, 7.81, 15.62, 23.43 and 31.25 dS m^{-1}. Plant height, number of tillers and the biomass of the plant were recorded. The height of the plant was decreased gradually with increased levels of salinity, but the effect was insignificant from 7.81 dS m^{-1} salinity level i.e. below this level plant height was not decreased. The tiller number of plants was decreased significantly at 15.62 dS m^{-1} of salinity level. It was also observed that the biomass of plant decreased significantly from 7.81 dS m^{-1} level of salinity.

The rice variety BR11 could be selected for the cultivation in coastal saline area as it can tolerate salinity at a higher level without significantly decreasing productivity (Gain *et al.,* 2004).

Response of rice cultivars Basmati-370 (salt-sensitive) and IR-6 (salt-tolerant) to 2 salinity levels [4.0 dS m^{-1} (control) and 10 dS m^{-1}) was investigated in a pot experiment in a wire-house. They took four harvests at an interval of 10 days each after imposition of salinity treatment and growth and chemical analyses of plant samples were carried out. Plant biomass showed an inverse relationship with increasing salinity levels. A general trend of decrease in dry weight of plant with salinity was noted in both cultivars. The mean values for dry weight were higher in Basmati-370 in the control condition. Analysis of variance showed a significant increase in Na^+ and Cl^- uptake with increasing salinity. Varietal means were highly significant and the maximum increase in Na^+ uptake (18.69%) was recorded in Basrnati-370. Harvest means showed that Na^+ uptake increased with the passage of time. However, at maturity there was a decline in Na^+ content in both cultivars. Cl^- increased with increasing salinity levels. Cultivar × treatment interaction revealed an increase in Na^+ and Cl^- uptake over the control in both cultivars. However, it was less in IR-6. The cultivars differed significantly for K^+, Ca^{2+}, P and N uptake. K^+ and Ca^{2+} uptake increased with the passage of time. Basmati-370 and IR-6 showed 45.20% and 15.55% decrease in Ca^{2+} over the control. P and N uptake increased with increasing salinity levels. An increase of 23.21% P uptake was recorded in Basmati-370 compared to IR-6. However, IR-6 accumulated higher (22.16%) N compared to Basmati-370 under the control and saline conditions (Zafar *et al.,* 2004).

It was suggested that the mutant variety maintained its superiority in various characteristics such as plant height, higher number of fertile panicles·plant $^{-1}$ and higher plant yield (Baloch *et al.,* 2003).

Critical saline concentration of soil and water for rice cultivation on a reclaimed saline soil was studied and it observed that the plant height of rice decreased in the 0.5% saline water in the soil (Choi *et al.,* 2003).

Dry matter production and the concentration of nutrients in rice (*Oryza sativa* L.) cultivars from soil adjusted to different levels of salinity under a greenhouse condition was evaluated. Soil salinity levels were induced by applying 0.34 $mol{\cdot}L^{-1}$ solution of NaCl which resulted in the following levels, control (0.29), 5, 10 and 15 dS m^{-1} conductivity of saturation extract. The effect of salinity on dry matter production varied from cultivar to cultivar. The concentrations of P and K in the tops of rice cultivars decreased with increasing soil salinity. But the concentrations of Na, Zn, Cu and Mn increased. Significant varietal differences were found in relation to salinity tolerance (Fageria, 2003).

It was suggested that reduction in grain number and grain weight of rice in salinized panicles was not merely due to reduction in pollen viability and higher accumulation of Na^+ and less K^+ in different floral parts but also due to higher accumulation of photosynthates (sugar) in primary and secondary panicle branches, panicle main stalk and panicle stem coupled with reduced activity of starch synthetase in developing grains (Abdullah *et al.*, 2002).

The effect of salinity stress (50 mM) on floral characteristics, yield components and biochemical and physiological attributes of the sensitive rice variety IR-28 was observed in an experiment. The results showed significant decrease in panicle weight, panicle length, primary branches per panicle. filled and unfilled grains, total grains and grain weight per panicle, 1000-grains weight and total grain weight per hill. They further observed significant reduction in both chlorophyll-a and chlorophyll-b content in different parts of the rice leaves at saline condition (Abdullah *et al.*, 2001).

Critical EC level of salinity for seedling growth was about 5 dS m^{-1} according to some researchers. They observed that dry matter, seedling height, root length and emergence of new roots of rice decreased significantly at an electrical conductivity value of 5–6 dS m^{-1} and during the early seedling stage, higher level of salinity caused rolling and withering of leaves, browning of leaf tips and ultimately death of seedlings. They speculated that both osmotic imbalance and Cl^{-} was responsible for suppress of the growth. These authors mentioned that the shoot growth was more suppressed than that of root and salt injury was more severe at high temperature (35°C) and low humidity (64%) due to increased transpiration and uptake of water and salt by rice plants. During vegetative period, the most common salinity effect was stunting of plant growth, whereas leaf withering was less apparent. At the reproductive stage, salinity depressed grain yields much more than that at the vegetative growth stage. These authors mentioned that at critical salinity levels straw yield was normal but produced little or no grain. The decrease in grain yield was found proportional to the salt concentration and the duration of the saline treatment. When the plants were continuously exposed to saline media, salinity affected the panicle initiation, spikelet formation, fertilization of florets and germination of pollen grains hence caused an increase in number of sterile florets. The greatest injurious effect was on the panicle. Salinity severely reduced the panicle length, number of primary branches per panicle, number of spikelets per panicle, seed setting percentage and panicle weight and reduced the grain yield. The weight of 1000-grains was also reduced. Salt injury resulted in the production of small grains in grain length, width and thickness. Most rice cultivars were severely injured in submerged soil cultures at EC of 8–10 dS m^{-1} at 25°C; sensitive ones were hurt even at 2 dS m^{-1}. At comparable EC's injury was less in sea water than in solutions of common salt, in neutral and alkaline soils than in acid soils, at 20°C than at 35°C and in 2-weeks old seedling than in 1-week old seedlings. Since rice plant is susceptible to salinity at transplanting and gains tolerance with age, they advised that aged seedlings (6-weeks old) be planted in saline fields (Alam *et al.*, 2001).

Observation of the effect of salinity on seed germination and seedling growth of rice varieties was carried out in an experiment. Fifteen rice cultivars were subjected to salt stress. They used different salt concentrations of 0, 4, 8 and 12 dS m^{-1}. The 15 cultivars were Pokkali. Dasal, Damodar, Vytilla 3, Vytilla 4, Vytilla 5, Panvel 1, USAR 2, CO 43, IR 28, MI 48, Improved White Ponni, CSR 10, SR 26 B and Canning 7. The germination percentage and seedling growth decreased with increasing salt concentration in all the cultivars. Among the cultivars. Pokkali and SR 26 B were the most tolerant to salt stress with respect to seed germination and seedling vigour, while improved White Ponni and IR 28 were the most susceptible (Thirumeni *et al.*, 2001).

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials and methods of the experiment with a brief description on experimental site, climate, soil, land preparation, planting materials, experimental design, fertilizer application, irrigation and drainage, intercultural operation, data collection, data recording and their analysis. The details of investigation for achieving stated objectives are described below.

3.1 Experimental period

The experiment was conducted at the net house of the Department of Agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020 to evaluate the effect of foliar application of micronutrients for increasing salinity tolerance in rice plants.

3.2 Geographical location

The experimental site was located at 23°46′ N latitude and 90°23′ E longitude with an altitude of 8.45 m.

3.3 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of “Madhupur Tract”, AEZ-28. This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as ‘islands’ surrounded by floodplain (FAO-UNDP, 1988). For better understanding, the experimental site is shown in the AEZ Map of Bangladesh in Appendix I (A).

3.4 Climate and weather

The geographical location of the experimental site was under the sub-tropical climate characterized by three distinct seasons. The monsoon or rainy season extends from May to October, which is associated with high temperature, high humidity and heavy rainfall. The winter or dry season extends from November to February which is associated with moderately low temperature and the pre-monsoon period or hot season from March to April which is associated with less rainfall and occasional gusty winds. Information regarding monthly maximum and minimum temperature, rainfall, relative humidity and sunshine during the period of study of the experimental site was collected from Bangladesh Meteorological Department, Dhaka and presented in Appendix III.

3.5 Soil

The soil which was collected for this pot experiment was silty clay in texture, red brown terrace soil type, olive–grey with common fine to medium distinct dark yellowish-brown mottles. Soil pH was 5.5 and had organic carbon 0.43% [Appendix II(B)]. The morphological characters of soil of the experimental pots are as following - Soil series: Tejgaon, General soil: Non-calcareous dark grey [Appendix I (B)]. The physicochemical properties of the soil are presented in Appendix II.

3.6 Planting materials

Five high yielding rice varieties namely, BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67 was used as planting material for the present study. These varieties are recommended for Boro season in Bangladesh. The seeds were collected from Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA). The feature of these varieties is presented below:

Name of Variety	:	BINA dhan10
Height	:	70–90 cm
Maturity	:	125–130 days
Number of grains spike^{-1}	:	35–40
Grain colour	:	Bright
1000 grains-weight	:	20–25 gm
Yield	:	7.50–8.50 t ha^{-1}
Salinity stress	:	Very tolerant

Name of Variety	:	BINA dhan8
Height	:	90–100 cm
Maturity	:	130–135 days
Number of grains spike^{-1}	:	40–50
Grain colour	:	Bright
1000 grain weight	:	20–25 gm
Yield	:	7.50–8.50 t ha^{-1}
Salinity stress	:	Very tolerant

Name of Variety	:	BRRI dhan29
Height	:	95 cm
Maturity	:	160 days
Number of grains spike^{-1}	:	90–100
Grain colour	:	White
1000 grain weight	:	13–15 gm
Yield	:	7.50 t ha^{-1}
Salinity stress	:	Sensitive

Name of Variety	:	BRRI dhan47
Height	:	105 cm
Maturity	:	152 days
Number of grains spike^{-1}	:	85–95
Grain colour	:	White coloured, White spot on grain
1000 grain weight	:	15–20 gm
Yield	:	6.00 t ha^{-1}
Salinity stress	:	Tolerant

Name of Variety	:	BRRI dhan67
Height	:	100 cm
Maturity	:	140–150 days

Number of grains spike^{-1}	:	105–110
Grain colour	:	White
1000 grain weight	:	20–25 gm
Yield	:	3.80–7.40 t ha^{-1}
Salinity stress	:	Tolerant

3.7 Treatments

The experiment consisted of three sets of treatments. The treatments were salinity levels, micronutrients and varieties of rice. Those are shown below:

Factor A: Salinity level (2)

i. S_1 = Control (No saline water)
ii. S_2 = 150 mM NaCl

Factor B: Micronutrients (4)

i. M_1 = Control (No micronutrients)
ii. M_2 = Zinc (0.5%)
iii. M_3 = Boron (0.5%)
iv. M_4 = Zinc (0.5%) + Boron (0.5%)

Factor C: Variety (5)

i. V_1 = BINA dhan10
ii. V_2 = BINA dhan8
iii. V_3 = BRRI dhan29
iv. V_4 = BRRI dhan47
v. V_5 = BRRI dhan67

3.8 Experimental design

The experiment was laid out in a RCBD factorial design with three (3) replications. Total 120 unit-pots were prepared for the experiment. Each pot was of required size.

3.9 Collection and preparation of soil

The soil of the experiment was collected from Sher-e-Bangla Agricultural University (SAU) farm. The soil was non-calcareous red brown terrace soil with loamy texture belonging to the AEZ Madhupur Tract. The collected soil was pulverized and inert materials, visible insect pest and plant propagules were removed. The soil was dried in the sun, crushed carefully and thoroughly mixed.

3.10 Sterilization of seed

Prior to germination seeds were surface sterilized with 1% sodium hypochlorite solution. The glass vials containing distilled water for seed rinsing was sterilized for 20 minutes.

3.11 Sowing and raising of seedlings in seed bed

The sterilized seeds were soaked with water for 24 hours and then washed thoroughly in clean water, and incubated for sprouting, which were sown in the wet seed bed on 28 November 2019. Chemical fertilizers namely urea, triple supper phosphate (TSP) and muriate of potash (MOP) at the rate of 120, 100 and 75 kg/ha, respectively were applied for N, P and K before final preparation of the seed bed. The fertilizers were applied one day before sowing the germinated seeds in the seed bed.

3.12 Preparation of pots

Soils of 10 kg pot^{-1} were fertilized with 40 g pot^{-1} cow dung, 1.72 g urea pot^{-1}, 1.44 g TSP pot^{-1}, 0.80 g MoP pot^{-1} at the rate of 15 t ha^{-1} cow dung, 215 kg ha^{-1} Urea, 180 kg ha^{-1} TSP and 100 kg ha^{-1} MoP. All of TSP, MoP and half of the urea were applied as basal dose. The remaining half of the urea dose was applied in each pot at 17 days after transplanting (DAT) of rice. Each pot was 21 cm deep with 24 cm diameter at the top where 1 layer of stone and 1 layer of sand were used. The pots were prepared on 23 December 2019 and fertilization was done on 26 December 2019. Considerable spacing was maintained among pots for convenience of cultural operation. Thereafter the pots containing soil were moistened with water.

3.13 Transplanting of seedlings in pot

Thirty days old seedlings of selected rice cultivars were transplanted in each of the respective pots on December 28, 2019. There were two hills in each pot.

3.14 Imposition of salinity stress

The plants were imposed to 150 mM NaCl solution as irrigated water. Control plants were grown in pots with normal irrigation water. The salt solutions were applied in the pots according to the treatments at 45 days after transplanting (DAT). To avoid osmotic shock, salt solutions were added in three equal instalments of 50 mM on 13 February, 17 February and 20 February 2019 cumulating at 150 mM until the expected conductivity was reached. After imposition of saline treatments, the electrical conductivity (EC) of each pot was measured every day with a PC meter and necessary adjustments were made by adding water.

3.15 Application of micronutrients

Micronutrients with different concentration were sprayed in the designated experimental pots on February 26, 2019. Zinc and Boron at the rate of 0.50% were applied as foliar application as per treatment.

3.16 Intercultural operation

Weeds grown in the pots were removed time to time in order to keep the pots weed and pest free. The soil was loosened whenever necessary during the period of experiment. Watering was done in each pot to hold the soil water level and salt concentration when needed.

3.17 Recording of data

The growth parameters during study were recorded at 90 DAT and at harvest from each pot and the yield and following other parameters were taken at harvest.

3.17.1 Crop growth parameters

a) Plant height
b) Tillers plant^{-1}
c) Leaf length
d) Leaf breadth

3.17.2 Yield contributing parameters

a) Filled grains hill^{-1}
b) Unfilled grains hill^{-1}
c) Panicle length
d) Weight of 1000-grains

3.17.3 Yield parameters

e) Grain yield hill^{-1}
f) Straw yield hill^{-1}
g) Biological yield hill^{-1}
h) Harvest index

3.18 Collection of data

3.18.1 Crop growth characters

3.18.1.1 Plant height measurement

The plant height of rice plant was considered from the top surface level of the pot to the tip of the longest leaf at booting stage and flowering stage. At maturity stage the plant height of rice plant count from the top surface level of the pot to the tipper end of the longest panicle. Plant height was measured three times at 60 DAT, 90 DAT and at harvest.

3.18.1.2 Tillers number

Number of tillers hill^{-1} was counted at 60 DAT, 90 DAT and at maturity stages by counting total tillers within a hill selected at random from each pot.

3.18.1.3 Leaf length

The length of leaf was measured with a meter scale from 3 selected leaves hill^{-1} and the average value was recorded. The length was measured from the base of the leaf attached to the stem to the tip.

3.18.1.4 Leaf breadth

The breadth of leaf was measured with a meter scale from 3 selected leaves hill^{-1} and the average value was recorded. The breadth was measured from the middle portion of a leaf where the width was maximum.

3.18.2 Yield contributing characters

3.18.2.1 Filled grains panicle^{-1}

The filled grains panicle^{-1} was collected randomly from five panicles hill^{-1} and then average number of filled grains panicle^{-1} was recorded.

3.18.2.2 Unfilled grains panicle^{-1}

The unfilled grains were collected randomly from five panicles hill^{-1} and then average number of unfilled grains panicle^{-1} was recorded.

3.18.2.3 Panicle length

The length of panicle was measured with a meter scale from five selected panicles hill^{-1} and the average value was recorded.

3.18.2.4 Weight of 1000-grains

One thousand cleaned dried grains were counted randomly from each pot and weighed by using a digital electric balance when the grains retained 12% moisture and the mean weight was expressed in gram.

3.18.3 Yield

3.18.3.1 Grain yield hill^{-1}

After proper drying, the grain yield hill^{-1} was recorded which had effective tillers from each pot and expressed on 12% moisture basis. Grain moisture content was measured by using a digital moisture meter.

3.18.3.2 Straw yield hill^{-1}

Straw yield was determined from each hill, after separating the grains from that corresponding hill. The sub-samples were oven dried to a constant weight.

3.18.3.3 Biological yield

Biological yield was determined using the following formula:
Biological yield (g hill^{-1}) = (Grain yield + Straw yield) g hill^{-1}

3.18.3.4 Harvest index (%)

Harvest Index denotes the ratio of economic yield to biological yield. Harvest index was determined with the following formula of Donald (1963):

$$\text{Harvest Index } (\%) = \frac{\text{Economic Yield (Grain weight)}}{\text{Biological Yield (Total dry weight)}} \times 100$$

It was expressed in percentage.

3.19 Statistical analysis

The collected data on different parameters were compiled and analysed following the analysis of variance (ANOVA) techniques by RCBD factorial design to find out the statistical significance of experimental results. The collected data were analysed by computer package program MSTAT-C software (Russell. 1986). The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 5% levels of probability.

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to evaluate the effect of foliar application of micronutrients for increasing salinity tolerance in rice plants. The results obtained from the study have been presented, discussed and compared in this chapter through table(s) and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix IV to VIII. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings. The analytical results have been presented in Table 1 through Table 20 and Figure 3 through Figure 29.

4.1 Effect of salinity on growth, yield attributes, yield and harvest index of boro rice

4.1.1 Plant height

Plant height of rice varieties ranged from 46.86 cm to 51.25 cm at 60 DAT, 59.55 cm to 65.56 cm at 90 DAT and 78.69 cm to 91.36 cm at harvest with significant effect of salinity on it (Table 1). At harvest, control treatment showed 16.10% taller plants than plants which received saline treatment. Islam (2018) reported that salt stress significantly reduced plant height of boro rice. Khanam *et al.* (2018) mentioned that plant height was negatively affected by salinity in rice plants. Hossain (2011) recorded that plant height was the highest at control salinity treatment and lowest in the maximum salinity level (12 dS m^{-1}) in rice plants. Sutradhar (2011) observed that the plant height of rice varieties was the highest in 0 dS m^{-1} level of salinity. Mahmmad *et al.* (2009) mentioned that on an average, plant height was reduced linearly with increasing soil salinity. Saleque *et al.* (2005) concluded that plant height of rice was seriously decreased by salinity level in salt affected soils. Gain *et al.* (2004) recorded that the height of the plant was decreased gradually with increased levels of salinity, but the effect was insignificant from 7.81 dS m^{-1} salinity level i.e. below this level plant height was not decreased. Khan *et al.* (2004) found that plant height, shoot and root growth were seriously decreased by salinity. Purnendu *et al.* (2004) stated that the height of the plant decreased gradually with increased levels of salinity, but the effect was insignificant from 7.81 dS m^{-1} salinity level. Choi *et al.* (2003) observed that the plant height of rice decreased in the 0.5% saline water in the soil. Young *et al.* (2003) showed that height of rice plant decreased at 0.5% saline water in the soil with low salinity level.

Table 1. Effect of salinity on plant height at different DAT of boro rice

Treatments	**Plant height (cm) at**		
	60 DAT	**90 DAT**	**Harvest**
S_1	51.25 a	65.56 a	91.36 a
S_2	46.86 b	59.55 b	78.69 b
LSD $_{(.05)}$	**4.00**	**4.82**	**11.07**
CV (%)	**5.05**	**4.65**	**7.86**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.2 Number of tillers hill^{-1}

Salinity treatment had significant impact on number of tillers hill^{-1} at 60 DAT, 90 DAT or at harvest (Table 2). At 60 DAT, tillers number of rice plants ranged from 9.78 to 10.93, at 90 DAT, tillers number ranged from 6.68 to 8.85 while it was 6.27 to 8.80 at harvest. Islam (2018) reported that salt stress significantly reduced number of tillers hill^{-1} and number of effective tillers hill^{-1} but increased the number of non-effective tiller hill^{-1} in boro rice. Khanam *et al.* (2018) mentioned that tiller number was negatively affected by salinity in rice field. Hossain (2011) reported that number of effective tillers hill^{-1} was the highest at control salinity treatment and the lowest in the maximum salinity level (12 dS m^{-1}) for different rice cultivars while number of non-effective tillers hill^{-1} increased with the increasing level of salinity. Sutradhar (2011) observed that the total tiller number and effective tiller of rice varieties was the highest in 0 dS m^{-1} level of salinity. Mahmmad *et al.* (2009) mentioned that on an average, number of tillers per plant was reduced linearly with increasing soil salinity. Gain *et al.* (2004) recorded the tiller number of rice plants was decreased significantly at 15.62 dS m^{-1} of salinity level. Purnendu *et al.* (2004) stated that the tiller number of plants decreased significantly at 15.62 dS m^{-1} salinity level.

Table 2. Effect of salinity on number of tillers hill^{-1} at different growth stages of boro rice

Treatments	Number of tillers hill^{-1} (no.) at		
	60 DAT	**90 DAT**	**Harvest**
S_1	10.93 a	8.85 a	8.80 a
S_2	9.78 b	6.68 b	6.27 b
LSD $_{(.05)}$	**0.26**	**2.16**	**2.42**
CV (%)	**1.55**	**17.97**	**18.15**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.3 Leaf length and leaf breadth

Leaf length of rice plants was significantly influenced by salinity treatment (Table 3). Leaf length ranged from 28.50 cm to 36.07 cm between control and saline treatment. Salinity treatment showed 26.56% shorter leaf than control treatment. Similarly, leaf breadth between control and saline treatment at harvest stage was also significant, which ranged from 1.45 cm to 1.74 cm between the treatments. Khanam *et al.* (2018) mentioned that leaf number and leaf area were negatively affected by salinity in rice. Khan *et al.* (2004) found that green leaf area and leaf weight were seriously decreased by salinity where leaf area was decreased more than other growth parameters.

Table 3. Effect of salinity on leaf length and breadth at harvest of boro rice

Treatment combinations	Leaf length at harvest (cm)	Leaf breadth at harvest (cm)
S_1	36.07 a	1.74 a
S_2	28.50 b	1.45 b
LSD (.05)	**6.50**	**0.26**
CV (%)	**12.14**	**9.96**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Sanity treatment had significant effect on number of filled grains panicle^{-1} of rice plants (Table 4). Number of filled grains panicle^{-1} ranged from 52.04 to 77.99 which showed that saline condition reduced 49.86% filled grain in compare to control treatment. The difference between the treatments regarding unfilled grains was also significant. Unfilled grains ranged from 9.48 in control condition to 17.07 in saline condition. Salinity treatment was recorded to produce more unfilled grains (80%) than control treatment. Islam (2018) reported that salt stress significantly reduced number of filled grains panicle^{-1} but increased the number of unfilled grain panicle^{-1} of boro rice plants. Hossain (2011) reported that number of filled grains panicle^{-1} was the highest at control salinity treatment and the lowest in the maximum salinity level (12 dS m^{-1}) for different rice cultivars while unfilled grains panicle^{-1} increased with the increasing level of salinity. Sutradhar (2011) observed that the filled grain of rice varieties was the highest in 0 dS m^{-1} level of salinity. Mahmmad *et al.* (2009) mentioned that on an average, number of grains per panicle was reduced linearly while grain sterility was increased with increasing soil salinity. With increased salinity, reduced number of grains panicle^{-1} was mainly found responsible for reduction in grain yield. Young *et al.* (2003) found that percentage of ripened grain dramatically decreased in 0.5% saline water in the soil low salinity level and 0.1% in soil with medium salinity level.

Table 4. Effect of salinity on yield contributing parameters of boro rice

Treatments	Filled grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	Panicle length (cm)	Weight of 1000-grains (g)
S_1	77.99 a	9.48 b	25.97 a	21.28 a
S_2	52.04 b	17.07 a	18.56 b	17.86 b
LSD $_{(.05)}$	**4.64**	**3.15**	**6.72**	**2.56**
CV (%)	**4.30**	**14.31**	**19.06**	**7.88**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.5 Panicle length

Panicle length of rice plants ranged from 18.56 cm (S_2) to 25.97 cm (S_1) with significant impact of salinity on it (Table 4). Saline condition reduced 39.92% length of panicle in compare to control condition. Islam (2018) reported that salt stress significantly reduced panicle length of boro rice. Hossain (2011) reported that panicle length was the highest at control salinity treatment and the lowest in the maximum salinity level (12 dS m^{-1}) for different rice cultivars. Mahmmad *et al.* (2009) mentioned that on an average, panicle length was reduced linearly with increasing soil salinity.

4.1.6 Weight of 1000-grains

Salinity treatment had significant effect on weight of 1000-grains of rice (Table 4). Weight of 1000-grains ranged from 17.86 (S_2) g to 21.28 g (S_1) where control treatment showed 19.14% heavier weight of 1000-grains than saline treatment. Islam (2018) reported that salt stress significantly reduced 1000-grains weight of boro rice. Hossain (2011) concluded that at the highest (12 dS m^{-1}) level of salinity, significantly better performance for thousand grain weight was given by Heera while BRRI dhan40 was the most badly affected one by salinity. Sutradhar (2011) observed that the grain weight of rice varieties was the highest in 0 dS m^{-1} level of salinity.

4.1.7 Grain yield

Grain yield (g $hill^{-1}$**)** of rice plants was significantly influenced by salinity stress (Table 5). Grain yield ranged from 20.71 g (S_2) to 32.77 g (S_1) where saline condition showed 58.23% reduction in grain yield in compare to control condition. Islam (2018) reported that salt stress significantly reduced grain yield of boro rice. Khanam *et al.* (2018) mentioned that salt stress caused a significant reduction in yield of rice. Hossain (2011) concluded that at the highest (12 dS m^{-1}) level of salinity, significantly better performance for grain yield $hill^{-1}$ was given by Heera while BRRI dhan40 was the most badly affected one by salinity.

Dauphina *et al.* (2010) observed that the yield decreased due to salinity was 20% for the rice cultivar. Muhammad *et al.* (2009) mentioned that on an average, grain yield plant^{-1}, was reduced linearly with increasing soil salinity.

Table 5. Effect of salinity on yield parameters and harvest index of boro rice

Treatments	Grain yield (g hill^{-1})	Straw yield (g hill^{-1})	Biological yield (g hill^{-1})	Harvest index (%)
S_1	32.77 a	28.75 a	61.52 a	53.26 a
S_2	20.71 b	21.69 b	42.40 b	48.84 b
LSD $_{(.05)}$	**6.90**	**6.90**	**10.88**	**2.34**
CV (%)	**15.27**	**16.50**	**12.57**	**2.70**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.1.8 Straw yield

Straw yield (g hill^{-1}**)** of rice plants was significantly affected by salinity stress (Table 5). Straw yield ranged from 21.69 g (S_2) to 28.75 g (S_1) where saline condition showed 32.54% reduction in straw yield in compare to control condition. Islam (2018) reported that salt stress significantly reduced straw yield of boro rice.

4.1.9 Biological yield

Biological yield (g hill^{-1}**)** of rice plants was significantly influenced by salinity stress (Table 5). Biological yield ranged from 42.40 g (S_2) to 61.52 g (S_1) where saline condition showed 45.09% reduction in biological yield in compare to control condition. Islam (2018) reported that salt stress significantly reduced biological yield of boro rice. Purnendu *et al.* (2004) stated that the biomass of the plant decreased significantly from 7.81 dS m^{-1} level of salinity.

4.1.10 Harvest index

Harvest index (%) of rice plants was significantly affected due to salinity stress condition (Table 5). Harvest index ranged from 48.84% (S_1) to 53.26% (S_2)

between the treatments. LingHe *et al.* (2000) stated that harvest indices of rice were significantly reduced by salinity at 3.4 dS m^{-1} or higher.

4.2 Effect of different micronutrients on growth, yield attributes, yield and harvest index of boro rice

4.2.1 Plant height

Plant height of rice varieties ranged from 46.33 cm (M_3) to 50.34 cm (M_4) at 60 DAT, 58.30 cm (M_2) to 67.12 cm (M_4) at 90 (DAT) which was significantly affected ($P \leq 0.05$) by different micronutrient applications (Table 6). M_4 treatment [Zinc (0.5%) + Boron (0.5%)] showed the tallest plant while M_2 treatment resulted in the shortest one. At 60 DAT and at 90 DAT, M_4 treatment showed 8.65% and 15.12% taller plants than plants which received no micronutrients, respectively. There was significant ($P \leq 0.05$) difference among the plant height due to application of different micronutrients at harvest stage which ranged from 75.10 cm (M_1) to 86.24 cm (M_4) (Table 6). M_4 treatment showed 14.83% taller plants than M_1.

Table 6. Effect of micronutrients on plant height at different growth stages of boro rice

Treatments	Plant height (cm) at		
	60 DAT	90 DAT	harvest
M_1	48.27 a	61.29 b	75.10 b
M_2	46.33 b	58.30 b	77.91 a
M_3	46.59 a	61.77 b	81.19 a
M_4	50.34 a	67.12 a	86.24 a
LSD (.05)	**4.00**	**4.82**	**11.07**
CV (%)	**5.05**	**4.68**	**8.27**

[M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.2.2 Number of tillers hill^{-1}

Different micronutrient treatments had significant impact on number of tillers hill^{-1} at 60 and 90 DAT and at harvest (Table 7). At 60 DAT, tillers number of rice plants ranged from 9.27 to 10.80; at 90 DAT, tillers number of rice plants ranged from 6.16 to 9.69 and at harvesting stage it ranged from 6.35 to 8.91

tillers hill^{-1}. At harvest, M_3 [Boron (0.5%)] treatment showed the highest value of number of tillers hill^{-1} (8.91) which was statistically similar to M_4 treatment. M_3 treatment produced 40.31% more tillers than the lowest tiller producing treatment M_2. Hafiz (2017) and Hyder *et al*. (2012) supported the findings of the present study.

Table 7. Effect of micronutrients on number of tillers hill^{-1} at different growth stages of boro rice

Treatments	**Tiller number (no.) at**		
	60 DAT	**90 DAT**	**harvest**
M_1	10.13 b	6.16 b	7.34 a
M_2	9.27 d	7.03 b	6.35 b
M_3	10.80 a	9.69 a	8.91 a
M_4	9.73 c	6.63 b	7.94 a
LSD $_{(.05)}$	**0.26**	**2.16**	**2.42**
CV (%)	**1.55**	**18.95**	**19.10**

[M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.2.3 Leaf length and leaf breadth

Leaf length of rice plants was significantly influenced by different micronutrient treatments (Table 8). Leaf length ranged from 30.53 cm (M_1) to 38.35 cm (M_3). M_3 treatment showed 25.61% lengthier leaf than control treatment. Leaf breadth values due to different micronutrients effect at harvest stage was also significant, which ranged from 1.34 cm (M_1) to 1.62 cm (M_4).

Table 8. Effect of micronutrients on leaf length and leaf breadth at harvest of boro rice

Treatments	**Leaf length at harvest (cm)**	**Leaf breadth at harvest (cm)**
M_1	30.53 b	1.34 b
M_2	33.29 a	1.52 a
M_3	38.35 a	1.54 a
M_4	37.08 a	1.62 a
LSD (.05)	**6.50**	**0.26**
CV (%)	**11.26**	**9.92**

[M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.2.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Micronutrient treatment had significant effect on number of filled grains panicle^{-1} of rice plants (Table 9). Number of filled grains panicle^{-1} ranged from 45.47 to 67.79 which showed that application of zinc + boron (M_4) increased 49.86% filled grain compare to zinc treatment alone (M_2). The difference among the treatments regarding unfilled grains was also significant. M_4 treatment was recorded to produce the least amount of unfilled grains panicle^{-1} (12.19) in compare to other treatments, while M_2 treatment had the maximum number of unfilled grains panicle^{-1} (18.23).

4.2.5 Panicle length

Panicle length of rice plants ranged from 15.45 cm (M_1) to 22.21 cm (M_4) with significant impact of micronutrient application on it (Table 9). M_4 treatment had the longest length of panicle in compare to other treatments.

4.2.6 Weight of 1000-grains

Micronutrient treatment had significant effect on weight of 1000-grains of rice (Table 9). Weight of 1000-grains ranged from 16.73 g to 20.93 g where M_4 [Zinc (0.5%) + Boron (0.5%)] treatment showed heavier weight of 1000-grains than other treatments including control.

Table 9. Effect of micronutrients on yield contributing parameters of boro rice

Treatments	Filled grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	Panicle length (cm)	Weight of 1000-grains (g)
M_1	58.59 b	16.03 a	15.45 b	18.16 b
M_2	45.47 c	18.23 a	16.87 a	16.73 b
M_3	55.72 b	15.31 a	19.85 a	18.72 ab
M_4	67.79 a	12.19 b	22.21 a	20.93 a
LSD (.05)	**4.64**	**3.15**	**6.72**	**2.56**
CV (%)	**4.92**	**12.31**	**20.63**	**8.28**

[M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.2.7 Grain yield

Grain yield (g $hill^{-1}$) of rice plants was significantly influenced by different micronutrient application (Table 10). Grain yield ranged from 19.30 g (M_2) to 30.24 g (M_4) where Zinc (0.5%) + Boron (0.5%) (M_4) combined application showed numerically the highest grain yield in compare to other treatments.

4.2.8 Straw yield

Straw yield (g $hill^{-1}$) of rice plants was significantly affected by different micronutrient application (Table 10). Straw yield ranged from 19.14 g (M_2) to 26.07 g (M_4) where M_4 treatment showed significantly the highest straw yield in compare to other treatments.

4.2.9 Biological yield

Biological yield (g $hill^{-1}$) of rice plants was significantly influenced by different level of micronutrients (Table 10). Biological yield ranged from 38.44 g (M_2) to 56.31 g (M_4) where Zinc (0.5%) + Boron (0.5%) (M_4) combined application showed numerically the highest biological yield in compare to other treatments.

Table 10. Effect of micronutrients on yield parameters and harvest index of boro rice

Treatments	Grain yield (g $hill^{-1}$)	Straw yield (g $hill^{-1}$)	Biological yield (g $hill^{-1}$)	Harvest index (%)
M_1	24.96 a	23.05 a	48.01 a	51.98 a
M_2	19.30 b	19.14 b	38.44 b	50.20 b
M_3	24.93 a	23.21 a	48.14 a	51.78 a
M_4	30.24 a	26.07 a	56.31 a	53.70 a
LSD (.05)	**6.90**	**6.90**	**10.88**	**2.34**
CV (%)	**16.53**	**18.00**	**13.66**	**2.69**

[M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.2.10 Harvest index

Harvest index (%) of rice plants was significantly affected due to micronutrient application on it (Table 10). Harvest index ranged from 50.20% (M_2) to 53.70% (M_4) among the treatments.

4.3 Effect of variety on growth, yield contributing, yield parameters and harvest index of boro rice

4.3.1 Plant height

Plant height of rice varieties ranged from 43.65 cm to 55.12 cm at 60 DAT, 55.28 cm to 66.66 cm at 90 (DAT) which was significantly affected ($P < 0.05$) by different varieties of rice (Table 11). V_2 treatment (BINA dhan8) showed the tallest plant while V_3 treatment (BRRI dhan29) resulted in the shortest one at both data recording intervals. There was significant ($p \leq 0.05$) difference among the plant height due to different varieties of rice at harvest stage which ranged from 69.15 cm to 95.68 cm (Table 11). BINA dhan8 was superior in terms of plant height compare to other varieties by some distance. Salam *et al.* (2019) observed that plant height was significantly higher in BRRI dhan67 than the other varieties but insignificant with BRRI dhan28 in medium to moderately saline soil condition. Chowhan *et al.* (2017) revealed that the highest plant was found with Binadhan-13. Islam (2012) reported that plant height was influenced by different rice varieties. Faurqe (2011) concluded that among the eleven genotypes, finally three genotypes (Patnai 23, Chapali and Soloi) were considered as moderately salt tolerant, on the basis of their growth contributing characteristics, such as plant height reduction.

Table 11. Effect of variety on plant height at different growth stages of boro rice

Treatments	Plant height (cm) at		
	60 DAT	**90 DAT**	**harvest**
V_1	49.59 b	64.51 a	85.89 ab
V_2	55.12 a	66.66 a	95.68 a
V_3	43.65 c	55.28 c	69.15 c
V_4	44.35 c	59.36 bc	76.60 bc
V_5	45.97 b	63.96 ab	78.80 bc
LSD $_{(.05)}$	**4.00**	**4.82**	**11.07**
CV (%)	**5.05**	**4.69**	**8.23**

[V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.3.2 Number of tillers hill^{-1}

Different varieties of rice had significant impact on number of tillers hill^{-1} at 60, 90 DAT and at harvest (Table 12). At 60 DAT, tillers number of rice plants ranged from 9.13 to 10.73. At 90 DAT, tillers number of rice plants ranged from 5.33 to 7.63. Similarly, different varieties showed significant influence on number of tillers hill^{-1} at harvesting stage which ranged from 5.97 to 8.41 tillers hill^{-1}. BINA dhan10 showed the highest value of number of tillers hill^{-1} (10.73, 7.63 and 8.41) at 60 DAT, 90 DAT and at harvest, respectively. Salam *et al.* (2019) observed that effective tiller number was significantly higher in BRRI dhan67 than the other varieties but insignificant with BRRI dhan28 in medium to moderately saline soil condition. Chowhan *et al.* (2017) revealed that total number of tillers per hill was found to be maximum in Binadhan-16. Islam (2012) reported that total tillers, effective tiller and number of non-effective tillers were influenced by different varieties of rice. Faurqe (2011) concluded that among the eleven genotypes, finally three genotypes (Patnai 23, Chapali and Soloi) were considered as moderately salt tolerant, on the basis of their yield contributing characteristics, such as total tiller reduction and effective tiller reduction.

Table 12. Effect of variety on tiller number at different growth stages of boro rice

Treatments	Tiller number (no.) at		
	60 DAT	**90 DAT**	**harvest**
V_1	10.73 a	7.63 a	8.41 a
V_2	9.43 c	5.33 b	5.97 b
V_3	10.03 b	6.93 a	7.52 a
V_4	9.13 d	6.03 a	7.01 a
V_5	10.73 a	7.63 a	8.33 a
LSD $_{(.05)}$	**0.26**	**2.16**	**2.42**
CV (%)	**1.55**	**18.87**	**19.25**

[V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.3.3 Leaf length and leaf breadth

Leaf length of rice plants was significantly influenced by different rice varieties (Table 13). Leaf length ranged from 29.03 cm (V_3) to 35.94 cm (V_5). Similarly, leaf breadth values were also significant due to different varietal effect at harvest stage, which ranged from 1.38 cm (V_3) to 1.66 cm (V_1).

Table 13. Effect of variety on leaf length and leaf breadth at harvest of boro rice

Treatments	Leaf length at harvest (cm)	Leaf breadth at harvest (cm)
V_1	35.37 a	1.66 a
V_2	34.34 a	1.56 a
V_3	29.03 b	1.38 b
V_4	33.11 a	1.58 a
V_5	35.94 a	1.55 a
LSD $_{(.05)}$	**6.50**	**0.26**
CV (%)	**11.55**	**9.94**

[V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.3.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Rice varieties had significant effect on number of filled grains per panicle of rice plants (Table 14). Number of filled grains per panicle ranged from 29.61 (V_1 = BINA dhan10) to 96.16 (V_5 = BRRI dhan67) which showed that variety BRRI dhan67 had 224.75% more filled grain compare to BINA dhan10. The difference among the varieties regarding Unfilled grains was also significant. BRRI dhan29 was recorded to produce the most amount of unfilled grains (33.09) in compare to other treatments, while BRRI dhan67 had the minimum number of unfilled grains panicle^{-1} (7.72). Chowhan *et al.* (2017) percent sterility of spikelets was the highest in Chakka Panja cultivar (33.28%). Salam *et al.* (2019) reported that spikelets per panicle and filled grain were significantly higher in BRRI dhan67 in compared to the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for medium to moderately saline soil condition. Islam (2012) reported that number of filled grains and number of unfilled grains were influenced by different varieties of rice. Faurqe (2011) concluded that among the eleven genotypes, finally three genotypes (Patnai 23, Chapali and Soloi) were considered as moderately salt tolerant, on the basis of their yield contributing characteristics, such as reduction of fertile grain per panicle.

Table 14. Effect of variety on yield contributing parameters of boro rice

Treatments	Filled grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	Panicle length (cm)	Weight of 1000-grains (g)
V_1	29.61 d	8.93 c	18.95 a	19.45 b
V_2	29.84 d	8.94 c	17.54 a	20.89 ab
V_3	54.89 c	33.09 a	21.42 a	13.86 c
V_4	75.67 b	19.09 b	16.26 b	16.31 c
V_5	96.16 a	7.72 c	23.02 a	22.20 a
LSD $_{(.05)}$	**4.64**	**3.15**	**6.72**	**2.56**
CV (%)	**4.89**	**12.22**	**20.63**	**8.32**

[V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.3.5 Panicle length

Panicle length of rice plants ranged from 16.26 cm to 23.02 cm with significant impact of rice varieties on it (Table 14). BRRI dhan67 had the longest length of panicle in compare to other treatments. Chowhan *et al.* (2017) revealed that the longest panicle length (25.49 cm) was found with Binadhan-13. Islam (2012) reported that panicle length was influenced by different varieties of rice.

4.3.6 Weight of 1000-grains

Different varieties of rice had significant effect on weight of 1000-grains of rice (Table 14). Weight of 1000-grains ranged from 13.86 g (BRRI dhan29) to 22.20 g (BRRI dhan67) where BRRI dhan67 showed heavier weight of 1000-grains than other varieties of rice. Salam *et al.* (2019) reported that 1000-grains weight was significantly higher in BRRI dhan67 in compared to the other varieties but insignificant with BRRI dhan28 ($p \leq 0.05$) for medium to moderately saline soil condition. Chowhan *et al.* (2017) revealed that thousand seed weight (26.03 g) was found to be maximum in Binadhan-16.

4.3.7 Grain yield

Grain yield (gm hill^{-1}**)** of rice plants was significantly influenced by different varieties of rice (Table 15). Grain yield ranged from 19.63 g to 26.93 g where BRRI dhan67 showed significantly the highest grain yield which was statistically similar to BRRI dhan29 (26.61 g) in compare to other varieties. Khanam *et al.* (2018) mentioned that salt stress caused a significant reduction in yield in both BR43 and BR55 cultivars of rice where the reduction in yield were found to be lower in BR55 than those in BR43 and BR55 showed higher salt tolerance than in BR43. Shirazy *et al.* (2019) revealed that BRRI dhan67 gave higher yield, gross margin and gross return than BINA dhan10 in the saline area. Chowhan *et al.* (2017) mentioned that in terms of grain yield, the highest was obtained from BRRI dhan71 (6.03 t ha^{-1}) followed by Binadhan-17 (5.05 t ha^{-1}); Binadhan-16 (4.51 t ha^{-1}); Binadhan-7; Binni dhan (4.44 t ha^{-1}); Chakka Panja (4.07 t ha^{-1}) and the lowest was recorded in Binadhan-13 (2.77 t ha^{-1}). Islam (2012) reported that grain yield was influenced by different varieties of rice. Faurqe (2011) concluded that among the eleven genotypes, finally three genotypes (Patnai 23, Chapali and Soloi) were considered as moderately salt tolerant, on the basis of their yield characteristics, such as grain yield and relative grain yield.

4.3.8 Straw yield

Straw yield (gm hill^{-1}**)** of rice plants was significantly affected by different rice varieties (Table 15). Straw yield ranged from 18.25 g to 25.16 g where BINA dhan10 showed the highest straw yield in compare to other treatments.

Table 15. Effect of variety on yield parameters and harvest index of boro rice

Treatments	Grain yield (g·hill^{-1})	Straw yield (g·hill^{-1})	Biological yield (g·hill^{-1})	Harvest index (%)
V_1	23.76 a	25.16 a	48.89 a	48.59 c
V_2	26.59 a	23.49 a	50.08 a	53.09 b
V_3	26.61 a	24.53 a	51.14 a	52.03 b
V_4	19.63 b	20.61 a	40.24 b	48.78 c
V_5	26.93 a	18.25 b	45.18 a	59.60 a
LSD $_{(.05)}$	**6.90**	**6.90**	**10.88**	**2.34**
CV (%)	**16.56**	**18.01**	**13.67**	**2.69**

[V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test.]

4.3.9 Biological yield

Biological yield (gm hill^{-1}**)** of rice plants was significantly influenced by different varieties of rice (Table 15). Biological yield ranged from 40.24 g to 51.14 g where BRRI dhan29 showed the highest biological yield which was statistically similar to BINA dhan8 (50.08 g) in compare to other treatments. Chowhan *et al.* (2017) reported that Binni dhan cultivar produced the highest biological yield (24.14 t ha^{-1}).

4.3.10 Harvest index

Harvest index (%) of rice plants was significantly affected due to varietal differences on it (Table 15). Harvest index ranged from 48.78% (V_4 = BRRI dhan47) to 59.60% (V_5 = BRRI dhan67) among the varieties.

4.4 Interaction effect of salinity and micronutrients on growth, yield attributes, yield and harvest index of boro rice

4.4.1 Plant height

Plant height of rice plants ranged from 45.29 cm to 51.25 cm at 60 DAT where it was 51.25 cm in control condition (Figure 3). At 90 DAT, it ranged from 58.30 cm to 67.12 cm where it was 63.56 cm in control condition. Generally, plant height decreased in salinity stress condition and gradually increased with application of micronutrients and reached up to 67.12 cm in S_2M_4 treatment combination. Thus, interaction effect of salinity and micronutrients showed significant impact on plant height of rice plants. Similar trend was observed at harvest stage where plant height ranged from 74.42 cm (S_2M_1) to 91.36 cm (S_1M_1). The tallest plant (91.26 cm) was seen under control condition (S_1M_1) and gradual increase of plant height from 74.42 cm to 81.24 cm was observed with the increase of micronutrient concentration under salinity stress.

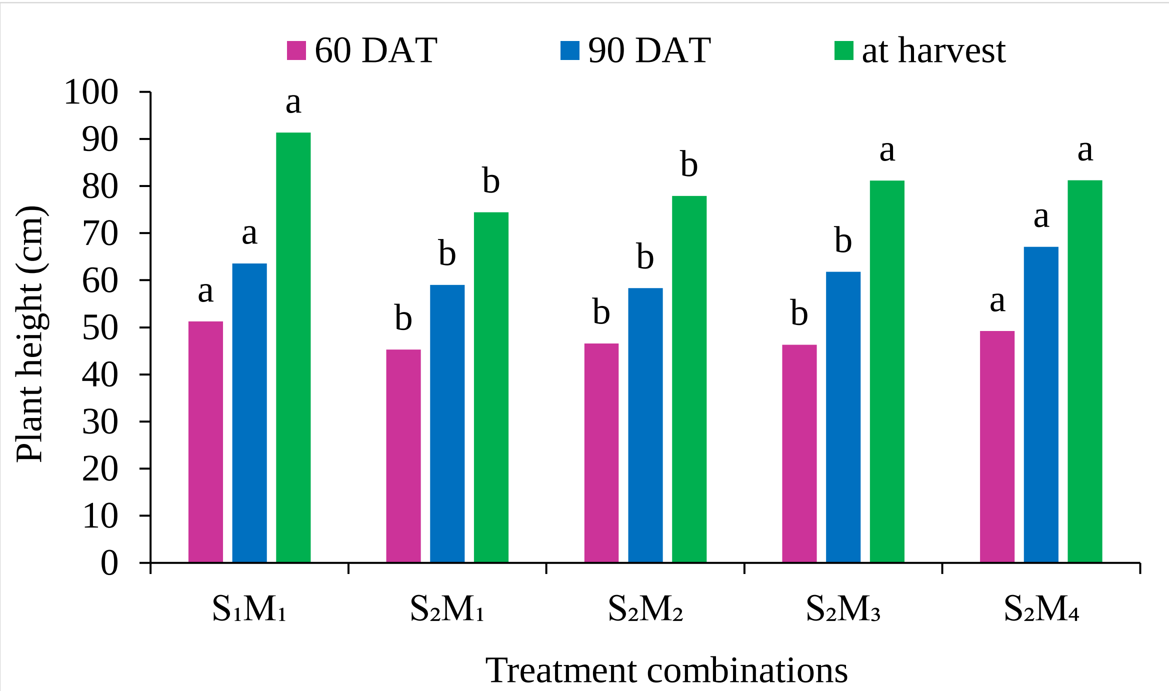

Figure 3. Interaction effect of salinity and micronutrients on plant height of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.2 Number of tillers hill^{-1}

Interaction effects of salinity level and micronutrients was significant on number of tillers hill^{-1} of rice plants at 60 DAT and at harvest but exerted non-significant effect at 90 DAT (Figure 4). At 60 DAT, number of tillers hill^{-1} ranged from 9.27 (S_2M_1) to 10.93 (S_1M_1) and at 90 DAT, number of tillers hill^{-1} ranged from 6.23 (S_2M_1) to 7.83 (S_1M_1) where control condition had more tillers than saline condition. At harvest, tillers number hill^{-1} ranged from 5.88 (S_2M_1) to 8.91 (S_2M_3) where S_2M_3 treatment combination showed slightly higher number of tillers than control.

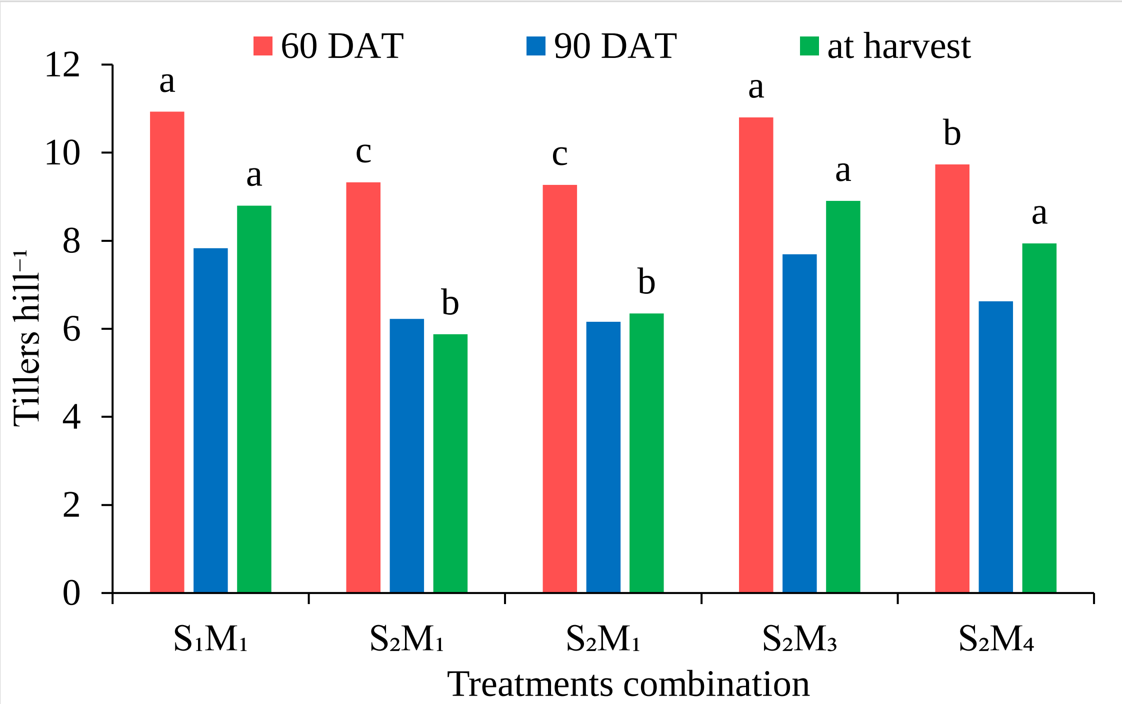

Figure 4. Interaction effect of salinity and micronutrients on number of tillers hill^{-1} of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.3 Leaf length and leaf breadth

Interaction of salinity and micronutrients exerted significant impact on leaf length of boro rice plants. Leaf length ranged from 29.50 cm (S_1M_1) to 38.35 cm (S_2M_3) where the shortest leaf was seen in control condition and the longest one from S_2M_3 treatment combination (Figure 5). But, at harvest stage, the impact of salinity and micronutrient interaction on leaf breadth was insignificant (Figure 6). Leaf breadth ranged from 1.52 cm (S_2M_2) to 1.62 cm (S_2M_4).

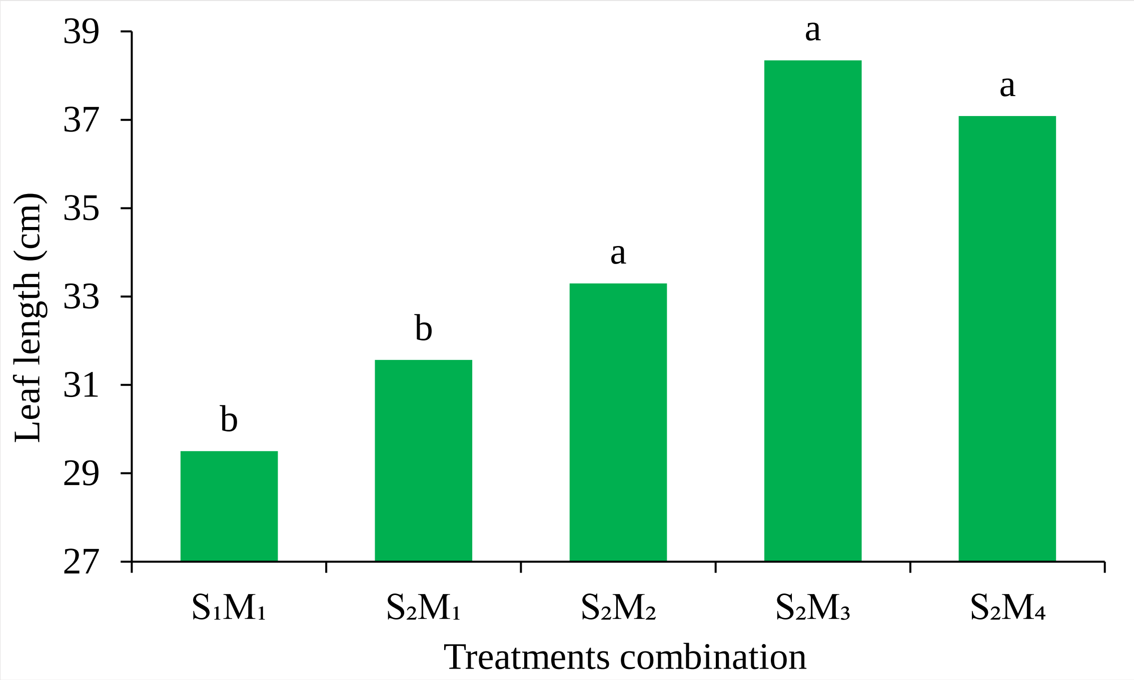

Figure 5. Interaction effect of salinity and micronutrients on leaf length of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

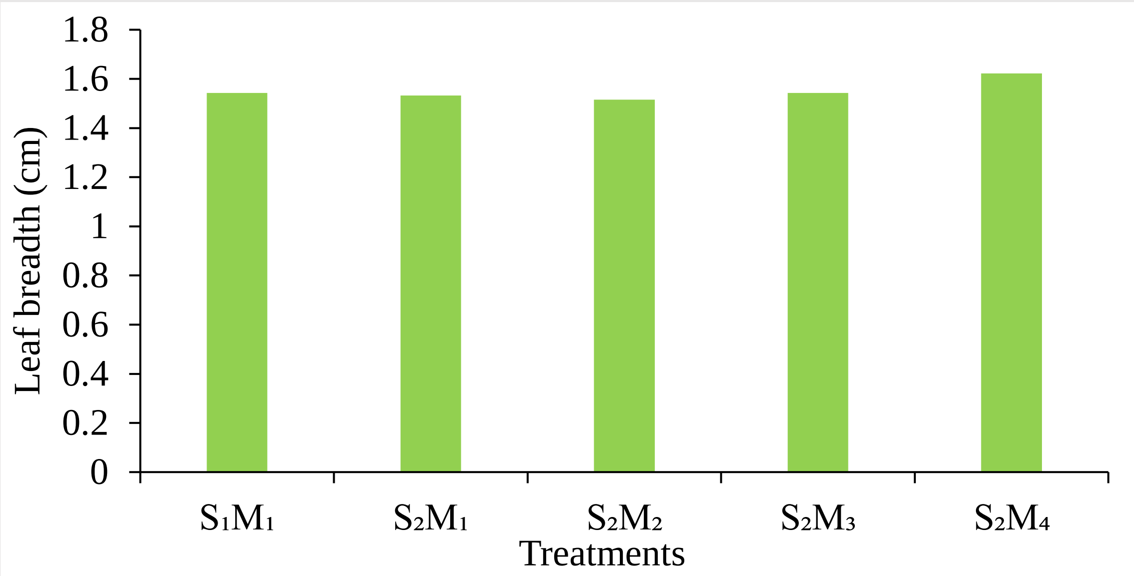

Figure 6. Interaction effect of salinity and micronutrients on leaf breadth of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Filled grains panicle^{-1} of boro rice ranged from 39.20 (S_2M_1) to 77.99 (S_1M_1) which was significantly affected by interaction of salinity and micronutrients (Figure 7). Control condition showed the maximum value for filled grains in compare to treatments with salinity stress condition. Similarly, unfilled grains per panicle ranged from 9.48 (S_1M_1) to 22.57 (S_2M_1) where saline condition exerted significant impact resulting in higher number of unfilled grains in compare to control condition.

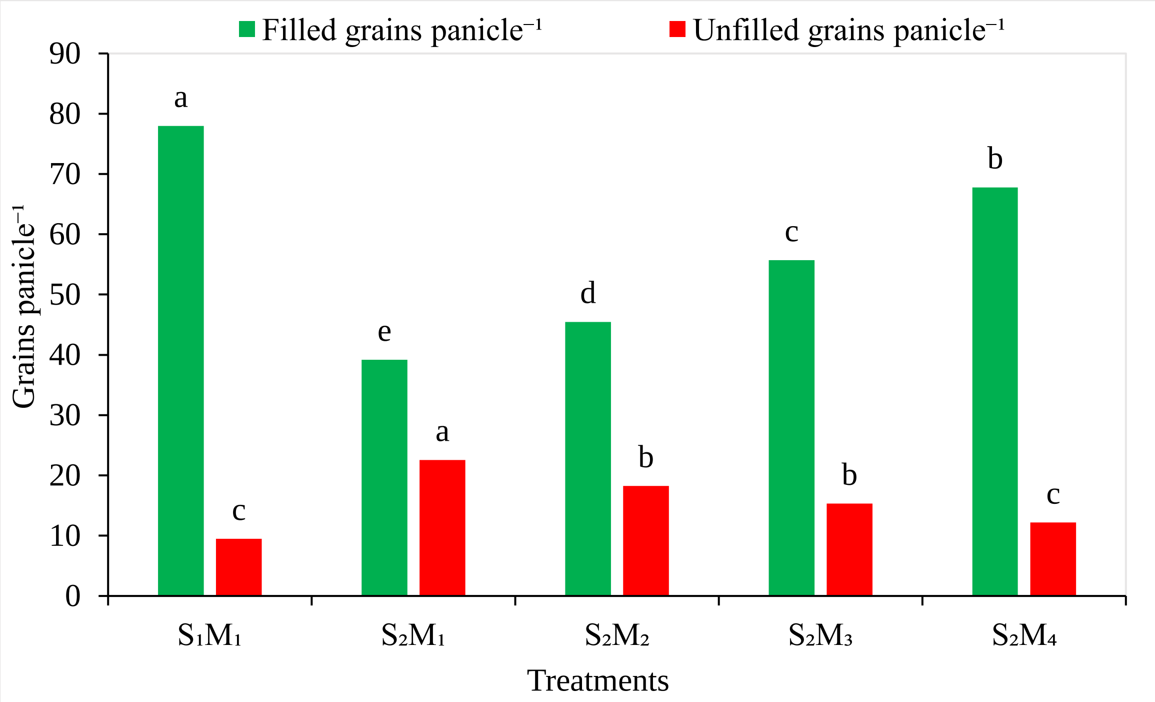

Figure 7. Interaction effect of salinity and micronutrients on filled and unfilled grains panicle^{-1} of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.5 Panicle length

Interaction of salinity and micronutrients exerted significant impact on panicle length of rice (Figure 8). Panicle length ranged from 15.31 cm (S_2M_1) to 23.97

cm (S_1M_1) where control condition had longer panicle in rice plants than salinity stressed condition.

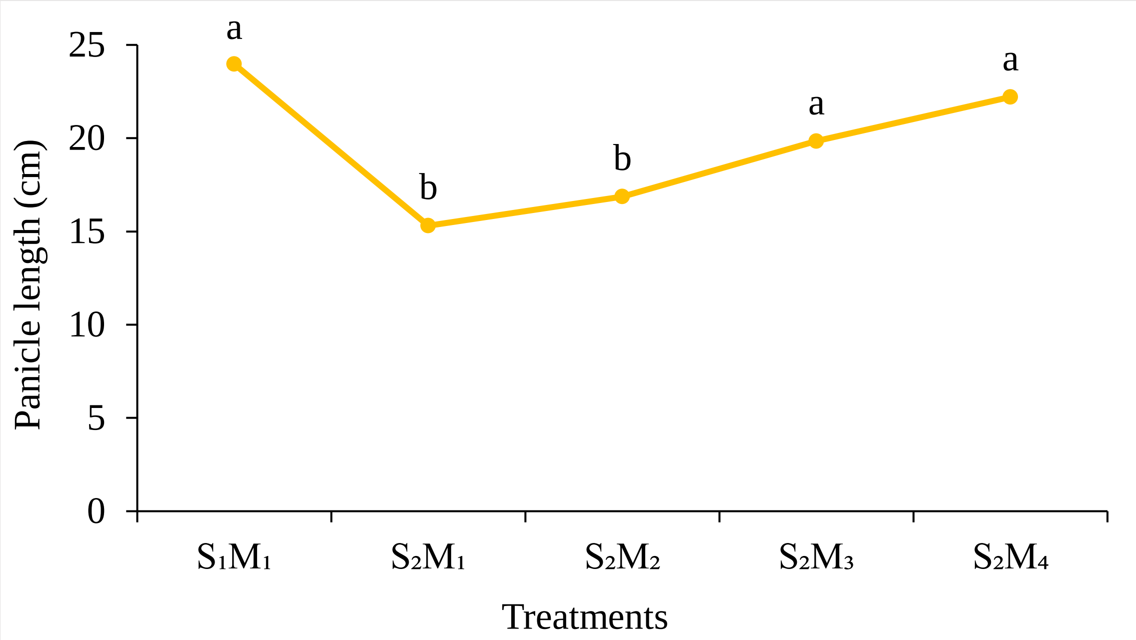

Figure 8. Interaction effect of salinity and micronutrients on panicle length of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.6 Weight of 1000-grains

Interaction of salinity and micronutrients exerted significant impact on weight of 1000-grains of rice (Figure 9). Weight of 1000-grains ranged from 15.05 g (S_2M_1) to 21.28 g (S_1M_1) where control condition had heavier weight of 1000-grains in rice plants than salinity stressed condition.

4.4.7 Grain yield

Interaction of salinity and micronutrients exerted significant effect on grain yield of rice (Figure 10). Grain yield ranged from 19.15 g (S_2M_1) to 30.77 g (S_1M_1) where control condition had higher grain yield of rice than salinity stressed condition. Combination of Boron and zinc showed higher yield of grain compared to individual application.

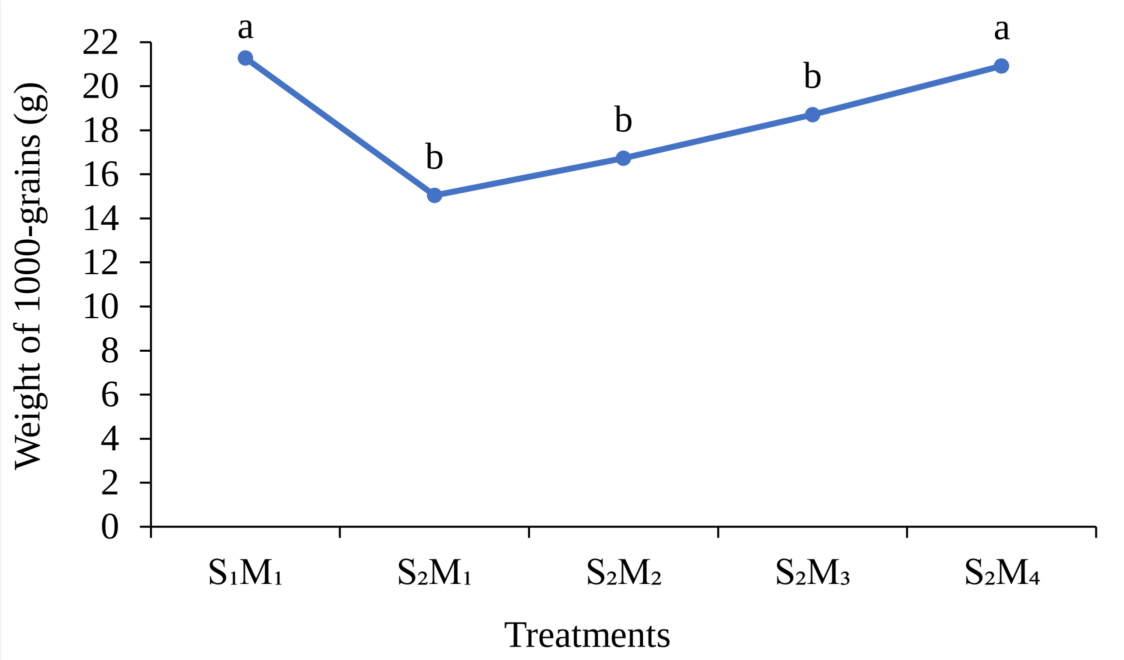

Figure 9. Interaction effect of salinity and micronutrients on weight of 1000-grains boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.8 Straw yield

Interaction of salinity and micronutrients exerted significant effect on straw yield of rice (Figure 10). Straw yield ranged from 17.36 g (S_2M_1) to 28.75 g (S_1M_1) where control condition had higher straw yield of rice than salinity stressed condition. Combination of Boron and zinc showed higher yield of straw compared to individual application.

4.4.9 Biological yield

Interaction of salinity and micronutrients exerted significant effect on biological yield of rice (Figure 10). Biological yield ranged from 36.27 g (S_2M_1) to 59.28 g (S_1M_1) where control condition had higher biological yield of rice than salinity stressed condition. Combination of Boron and zinc showed higher biomass yield of rice compared to individual application.

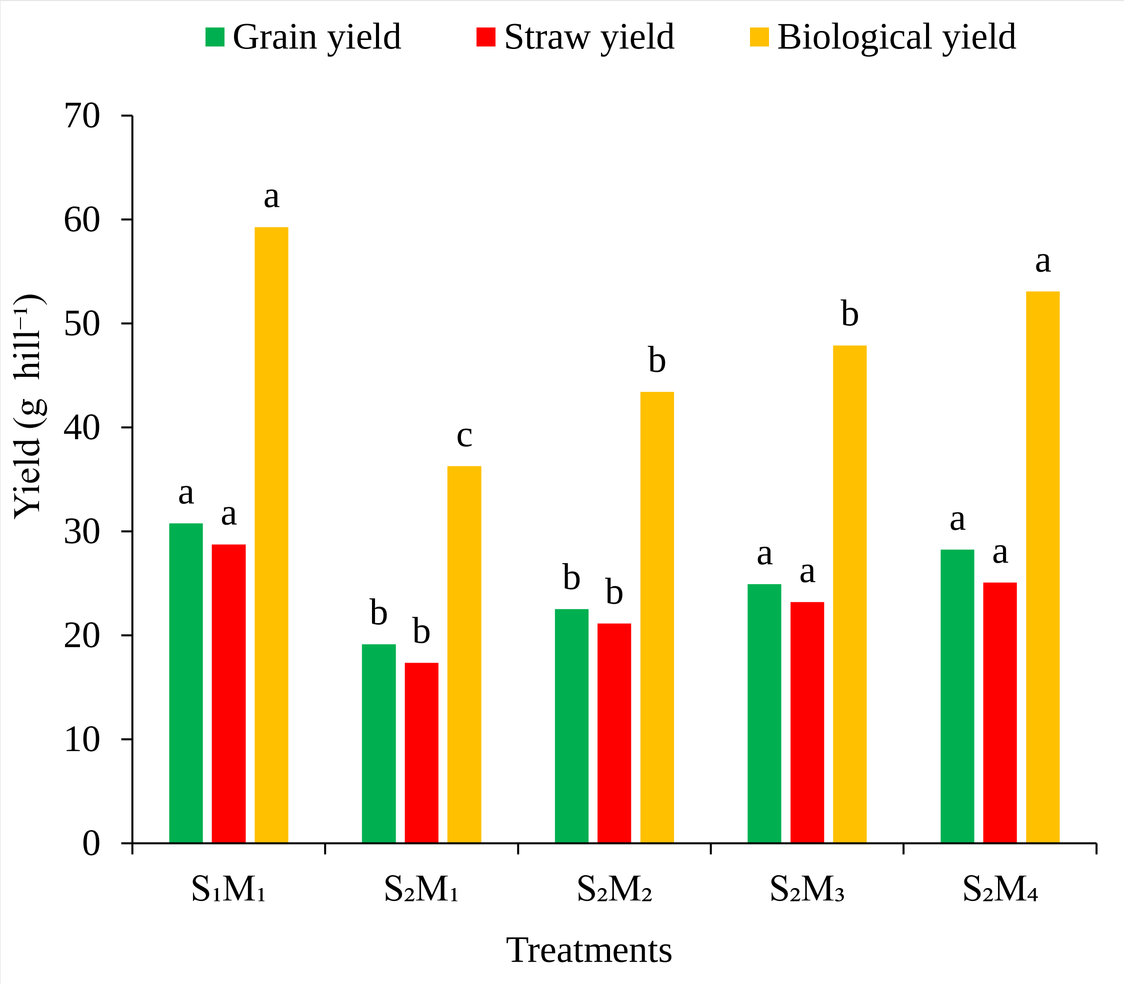

Figure 10. Interaction effect of salinity and micronutrients on grain, straw and biological yield boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.4.10 Harvest index

Interaction of salinity and micronutrients did not have any significant effect on harvest index of rice (Figure 11). Harvest index ranged from 51.96% (S_2M_2) to 53.36 % (S_2M_1). Application of boron and zinc micronutrients combinedly increased harvest index of rice compared to individual application.

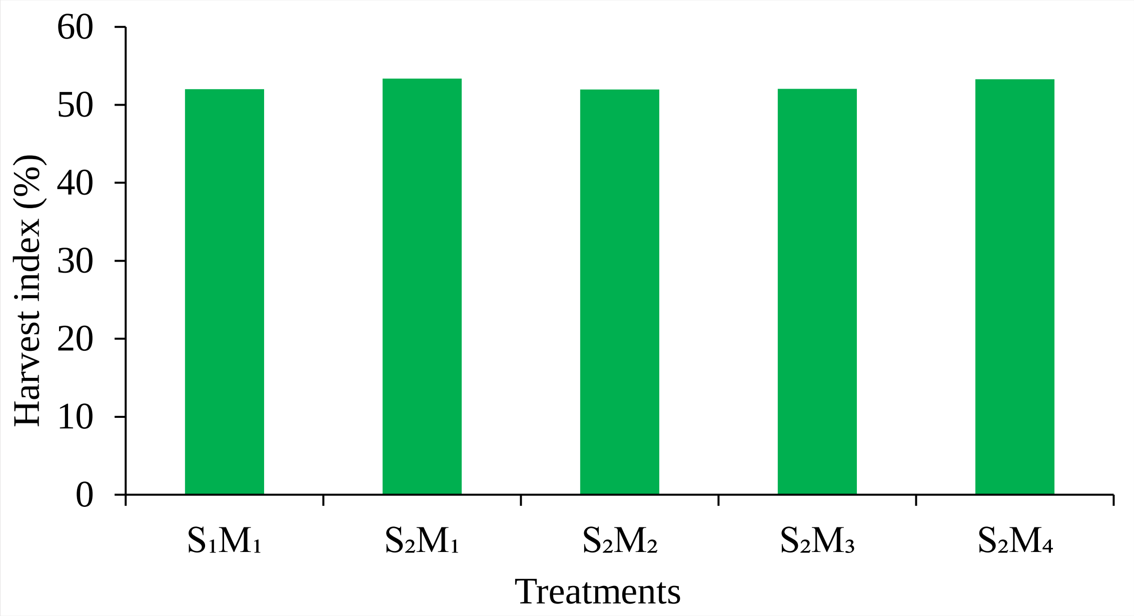

Figure 11. Interaction effect of salinity and micronutrients on harvest index boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5 Interaction effect of salinity and variety on growth, yield attributes, yield and harvest index of boro rice

4.5.1 Plant height

Plant height of rice plants ranged from 42.18 cm (S_2V_3) to 60.51 cm (S_1V_2) at 60 DAT and 54.19 cm (S_2V_3) to 70.37 cm (S_1V_2) at 90 DAT (Figure 12). Generally, it decreased in salinity stress condition irrespective of the varieties. Thus, interaction effect of salinity and variety showed significant impact on plant height of rice plants. Similar trend of plant height was observed at harvest stage where plant height ranged from 66.30 cm (S_2V_3) to 101.38 cm (S_1V_2). The tallest plant (101.38 cm) was seen under control condition (S_1V_2) and gradual decrease of plant height from 101.38 cm to 66.30 cm was observed with the imposition of salinity stress on all the rice varieties.

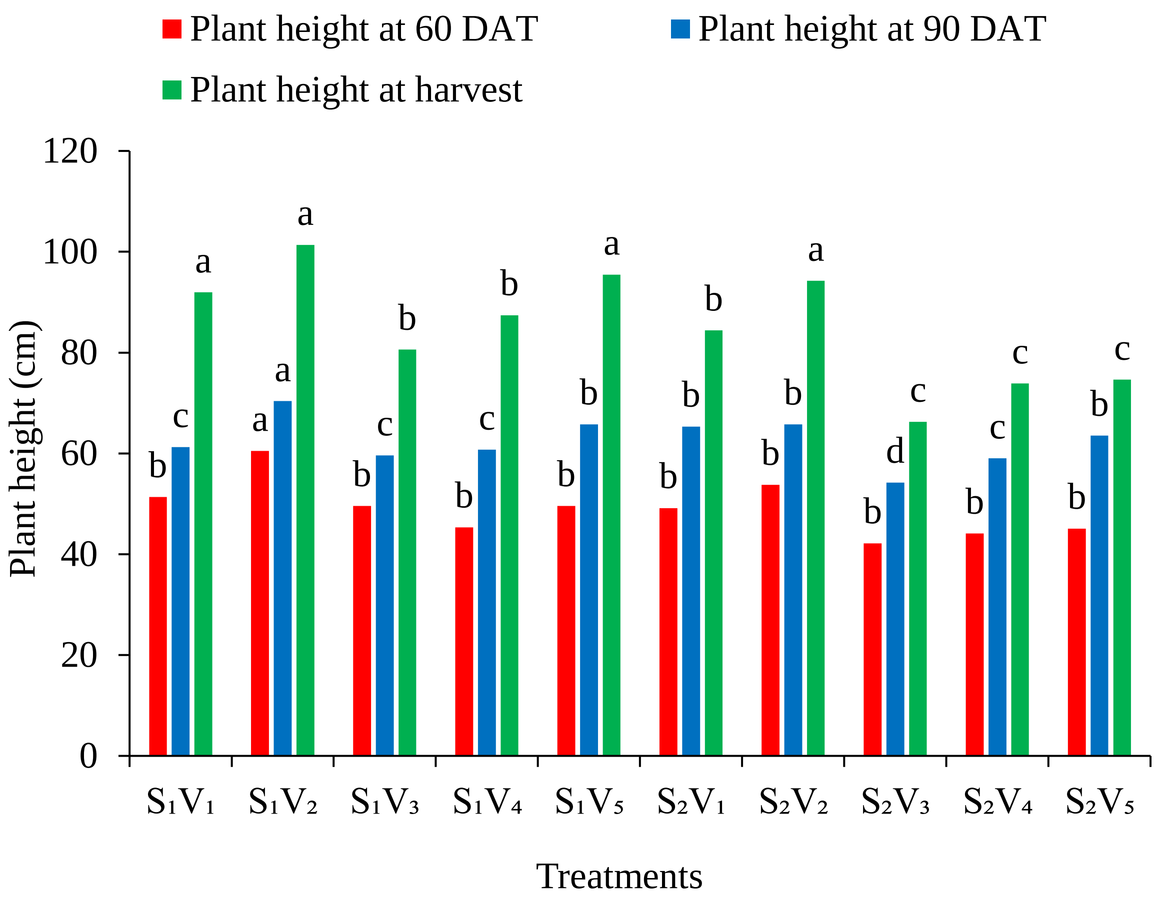

Figure 12. Interaction effect of salinity and variety on plant height of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.2 Number of tillers hill^{-1}

Interaction effects of salinity stress and varieties of rice was significant on number of tillers hill^{-1} of rice plants at 60 DAT, 90 DAT and at harvest (Figure 13). At 60 DAT, number of tillers hill^{-1} ranged from 9.01 (S_2V_2) to 11.63 (S_1V_5) and at 90 DAT, number of tillers hill^{-1} ranged from 5.53 (S_1V_4) to 9.03 (S_1V_1) where control condition had more tillers than saline condition. At harvest, tiller number ranged from 6.19 (S_2V_2) to 10.51 (S_1V_1) where control treatment combined with rice variety showed higher number of tillers in compare to varieties under salinity stress.

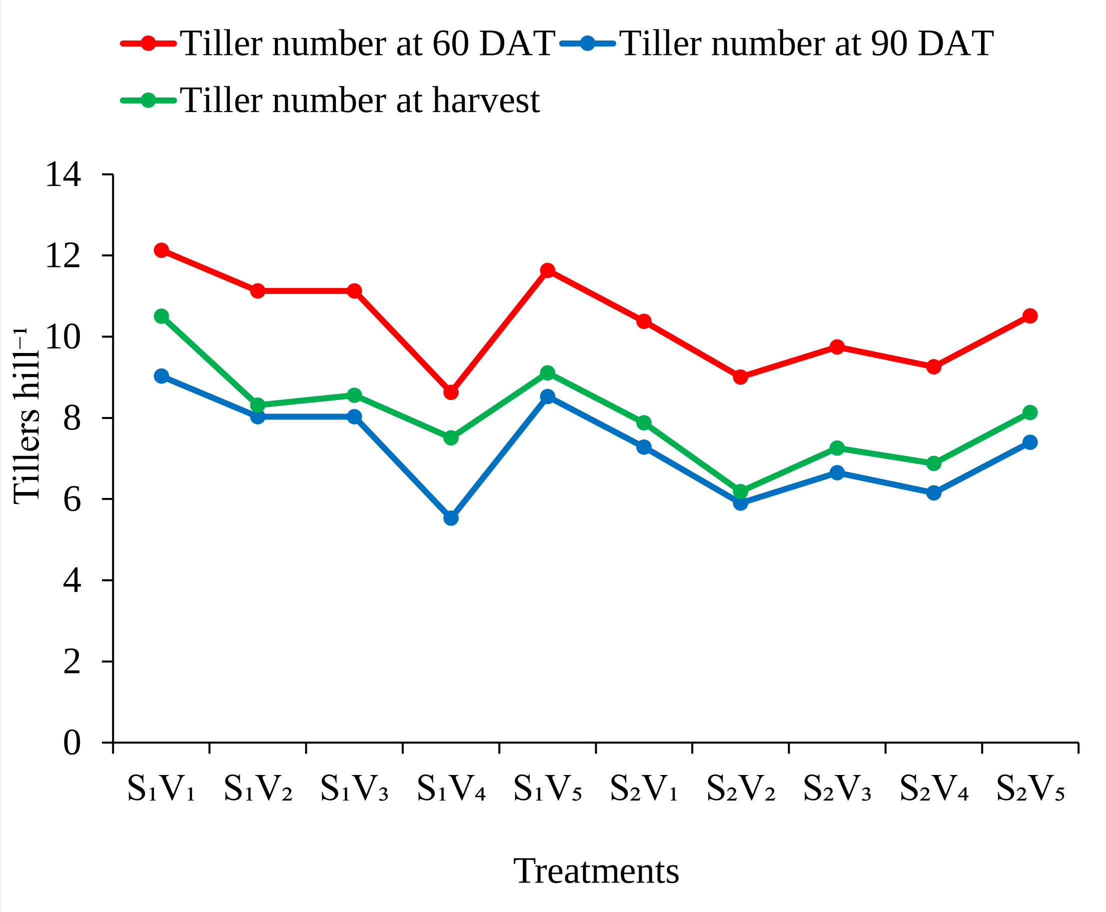

Figure 13. Interaction effect of salinity and variety on number of tillers hill^{-1} of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.3 Leaf length and leaf breadth

Interaction of salinity and variety exerted significant impact on leaf length and leaf breadth of boro rice plants. Leaf length ranged from 26.78 cm (S_1V_3) to 37.62 cm (S_2V_1) (Figure 14). At harvest stage, the impact of salinity and variety interaction on leaf breadth was significant where leaf breadth ranged from 1.37 cm (S_2V_3) to 1.71 cm (S_2V_1) (Figure 15).

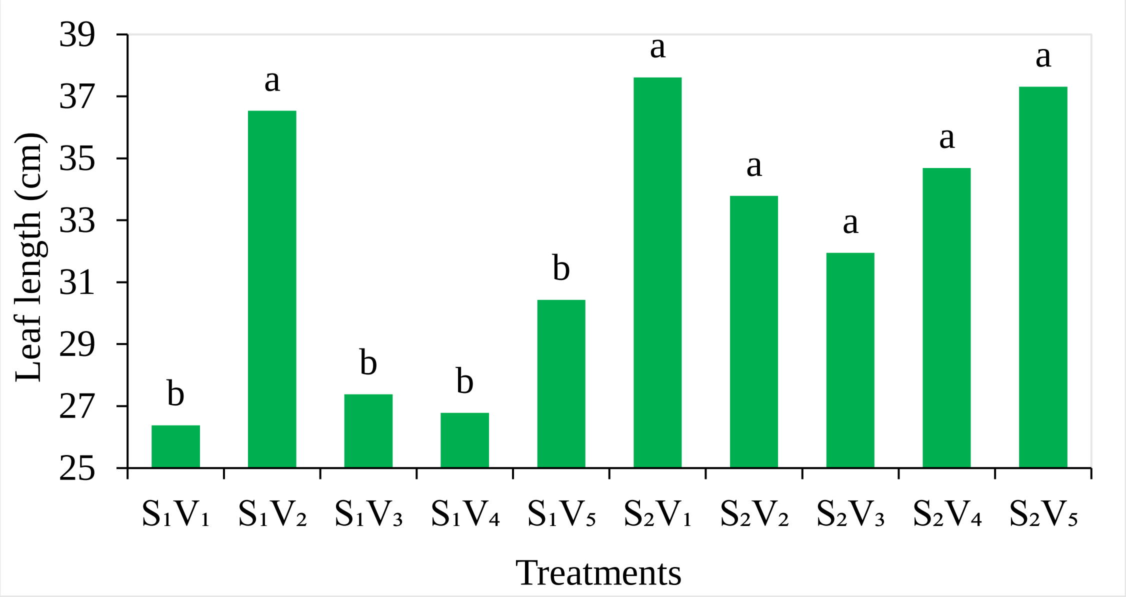

Figure 14. Interaction effect of salinity and variety on leaf length of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

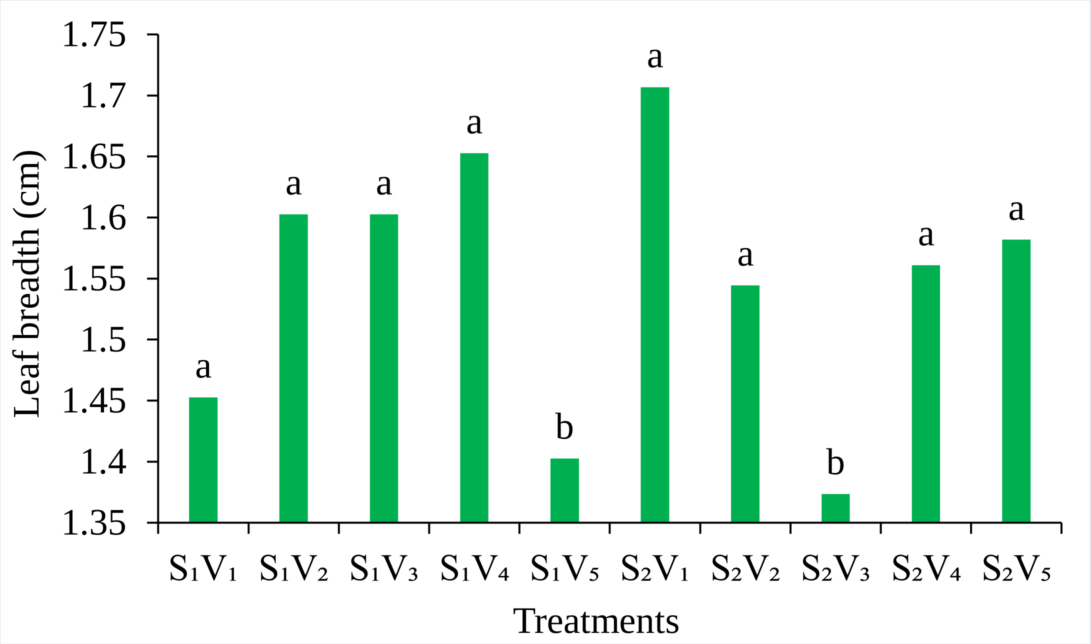

Figure 15. Interaction effect of salinity and variety on leaf breadth of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Filled grains panicle^{-1} of boro rice ranged from 23.86 (S_2V_1) to 103.32 (S_1V_4) which was significantly affected by interaction of salinity and variety (Figure 16). Control condition showed the maximum value for filled grains in compare to treatments with salinity stress condition irrespective of varieties. Similarly, unfilled grains panicle^{-1} ranged from 2.36 (S_1V_2) to 34.20 (S_2V_3) where saline condition exerted significant impact resulting in higher number of unfilled grains in compare to control condition irrespective of rice varieties (Figure 16).

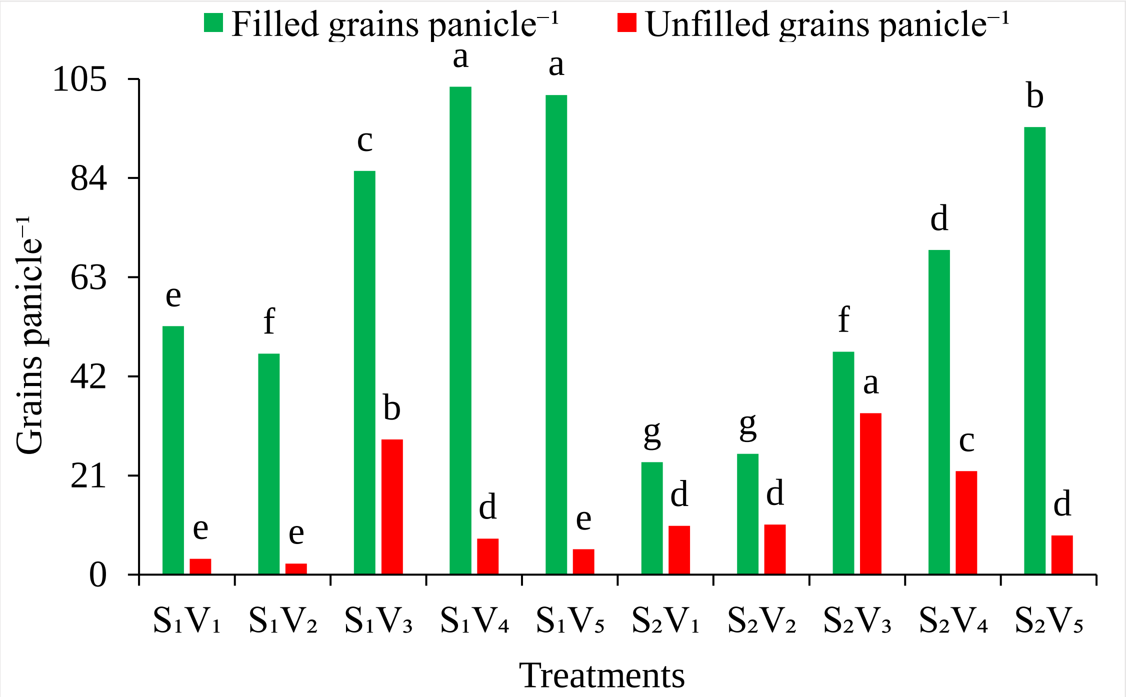

Figure 16. Interaction effect of salinity and variety on filled and unfilled grains panicle^{-1} of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.5 Panicle length

Interaction of salinity and rive variety exerted significant impact on panicle length of rice (Figure 17). Panicle length ranged from 15.72 cm (S_2V_4) to 25.59

cm (S_1V_5) where control condition had longer panicle in rice plants than salinity stressed condition irrespective of the varieties of rice.

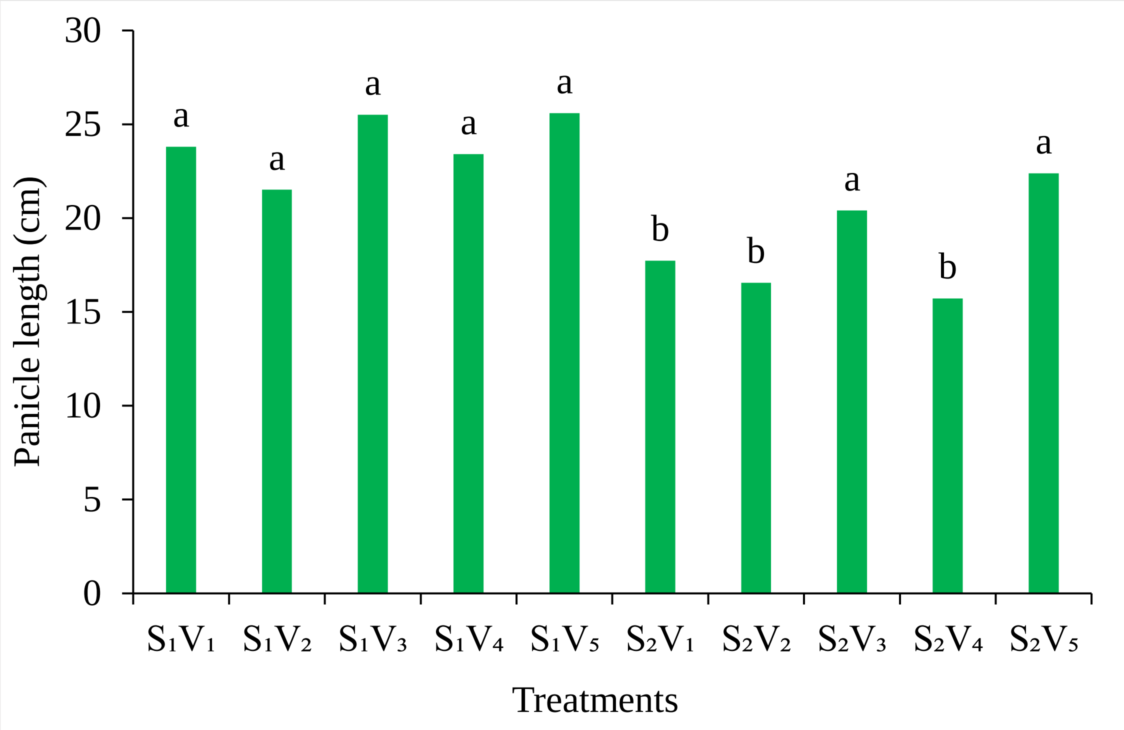

Figure 17. Interaction effect of salinity and variety on panicle length of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.6 Weight of 1000-grains

Interaction of salinity and variety of rice exerted significant impact on weight of 1000-grains of rice (Figure 18). Weight of 1000-grains ranged from 13.18 g (S_2V_3) to 23.54 g (S_1V_4) where control condition had heavier weight of 1000-grains in rice plants than varieties under salinity stressed condition. Hossain (2011) concluded that at the highest (12 dS m^{-1}) level of salinity, significantly better performance for 1000-grains weight was given by Heera while BRRI dhan40 was the most badly affected one by salinity.

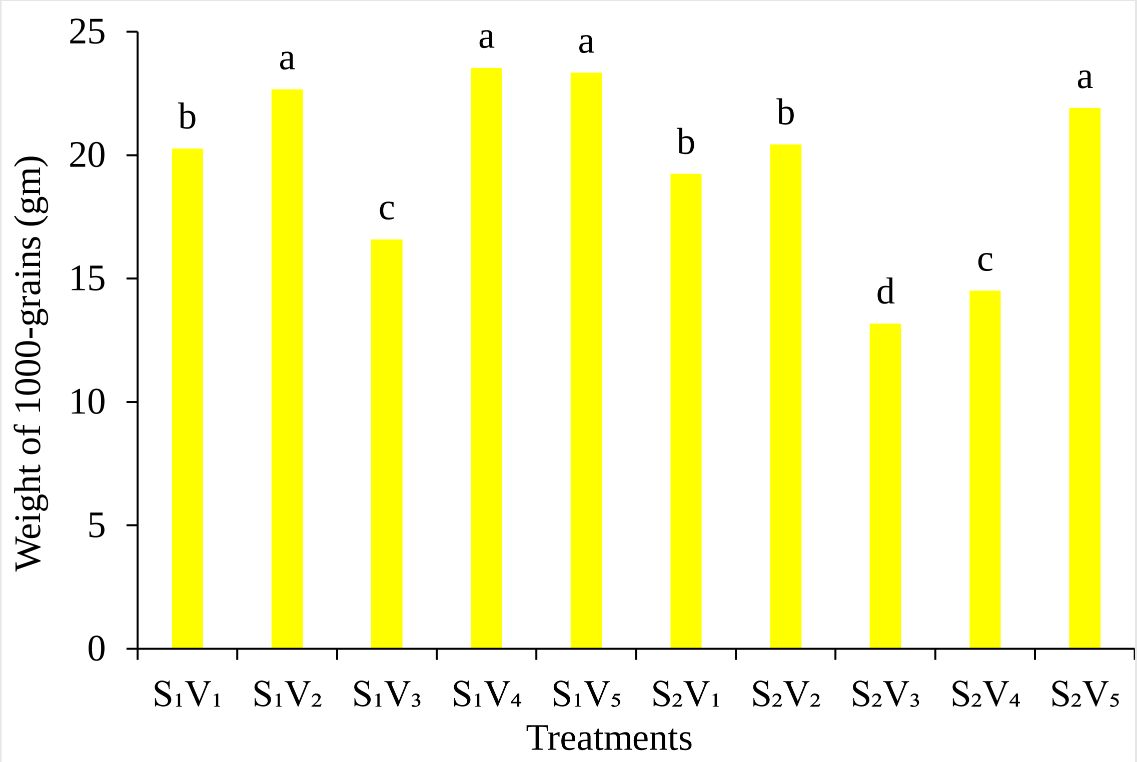

Figure 18. Interaction effect of salinity and variety on weight of 1000-grains of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.7 Grain yield

Interaction of salinity and rice variety exerted significant effect on grain yield of rice (Figure 19). Grain yield ranged from 20.53 g (S_2V_4) to 32.90 g (S_1V_2) where varieties under control condition had higher grain yield of rice than varieties salinity stressed condition. Hossain (2011) concluded that at the highest (12 dS m^{-1}) level of salinity, significantly better performance for grain yield hill^{-1} was given by Heera while BRRI dhan40 was the most badly affected one by salinity.

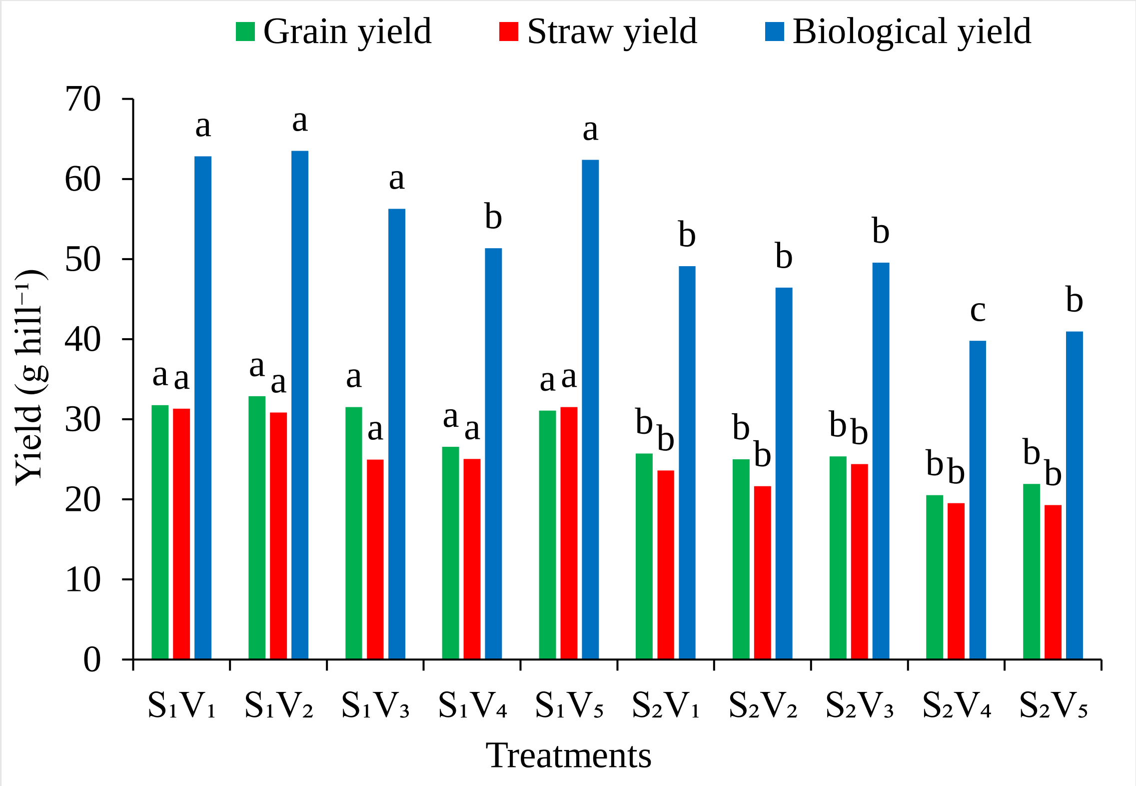

Figure 19. Interaction effect of salinity and variety on grain, straw and biological yield of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.8 Straw yield

Interaction of salinity and rice variety exerted significant effect on straw yield of rice (Figure 19). Straw yield ranged from 19.28 g (S_2V_5) to 31.54 g (S_1V_5) where rice varieties under control condition had higher straw yield than rice varieties under salinity stressed condition.

4.5.9 Biological yield

Interaction of salinity and rice variety exerted significant effect on biological yield of rice (Figure 19). Biological yield ranged from 39.79 g (S_2V_4) to 63.52 g (S_1V_2) where varieties under control condition had higher biological yield of rice than varieties under salinity stressed condition.

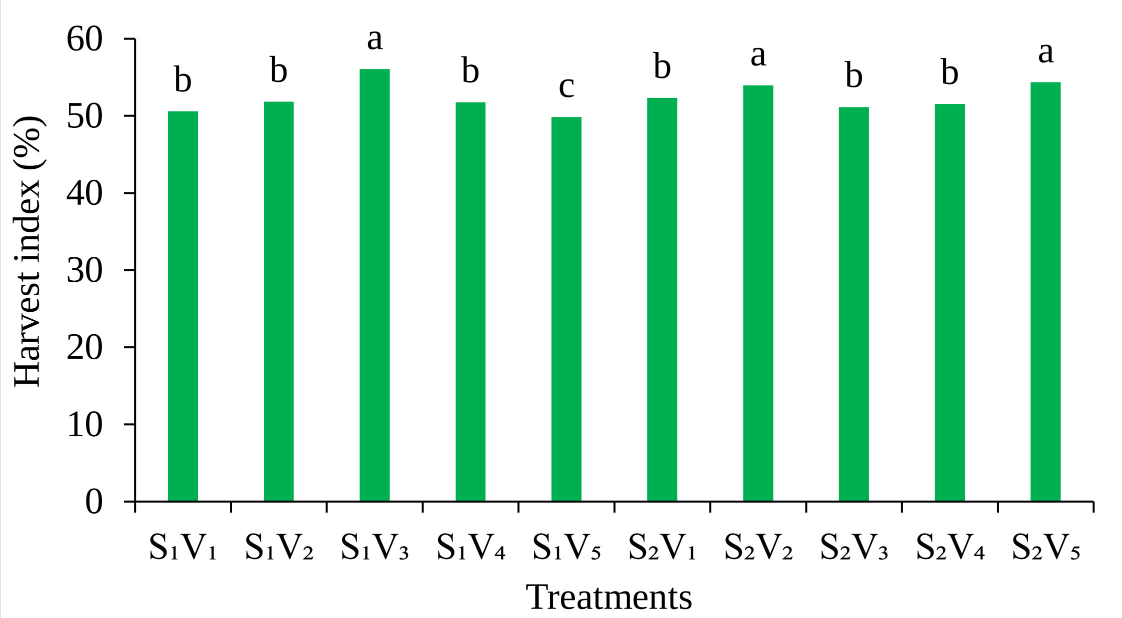

Figure 20. Interaction effect of salinity and variety on harvest index of boro rice. [S_1 and S_2 indicate control and 150 mM NaCl, respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.5.10 Harvest index

Interaction of salinity and rice variety had significant effect on harvest index of rice (Figure 20). Harvest index ranged from 49.86% (S_1V_5) to 56.07% (S_1V_3). Rice varieties under control condition had higher harvest index values than varieties under salinity stressed condition.

4.6 Interaction effect of micronutrients and variety on growth, yield attributes, yield and harvest index of boro rice

4.6.1 Plant height (cm)

Plant height of rice plants ranged from 41.33 cm (M_2V_3) to 59.71 cm (M_4V_2) at 60 DAT and 50.87 cm (M_2V_3) to 72.70 cm (M_3V_2) at 90 DAT (Figure 21). Generally, plant height increased with the application of micronutrients and reached up to 72.70 cm in M_3V_2 treatment combination at 90 DAT. Thus, interaction effect of micronutrients and rice variety showed significant impact on plant height of rice plants. Similar trend was observed at harvest stage where plant height ranged from 62.38 cm (M_2V_3) to 100.36 cm (M_4V_2).

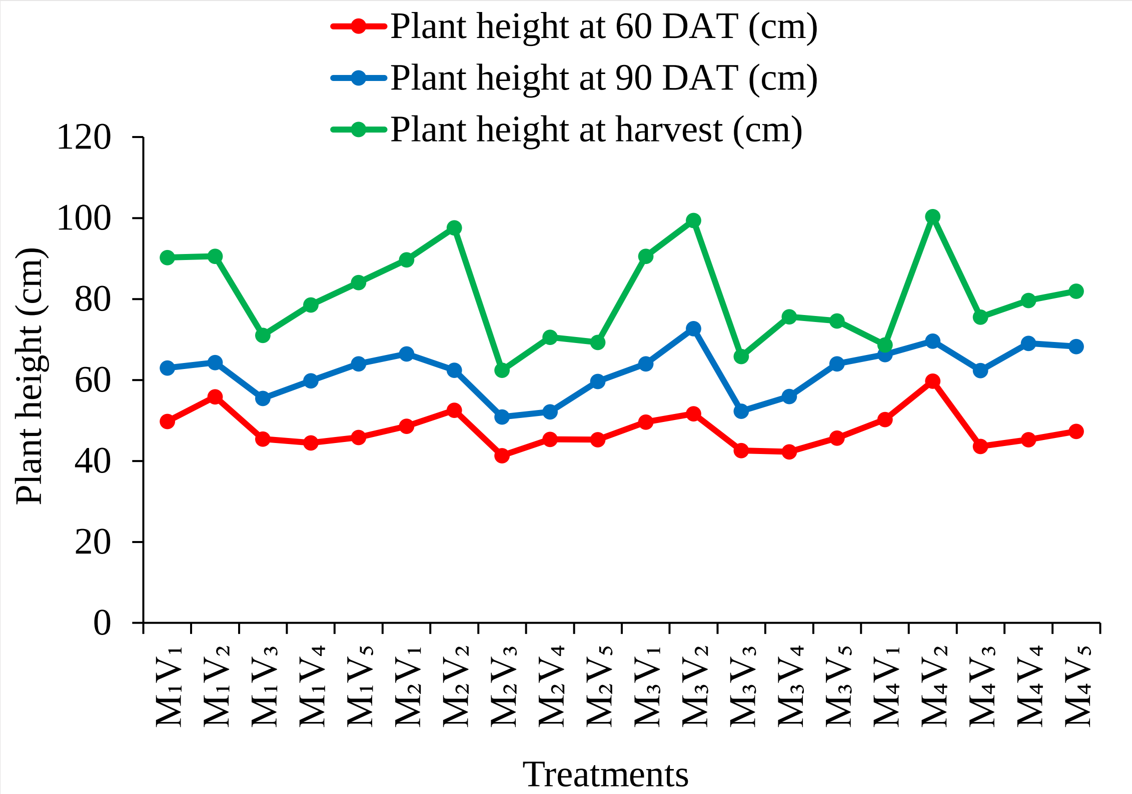

Figure 21. Interaction effect of micronutrients and variety on plant height of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.2 Number of tillers hill^{-1}

Interaction effects of micronutrients and variety was significant on number of tillers hill^{-1} of rice plants at 60 and 90 DAT and at harvest (Figure 22). At 60 DAT, number of tillers hill^{-1} ranged from 8.13 (M_4V_2) to 11.80 (M_3V_2 and M_3V_5). At 90 DAT, number of tillers hill^{-1} ranged from 5.03 (M_4V_2) to 8.69 (M_3V_2 and M_3V_5). At harvest, tiller number ranged from 5.48 (M_2V_2) to 10.51 (M_3V_5). Rice varieties which were applied with micronutrients had more tillers than varieties without micronutrients.

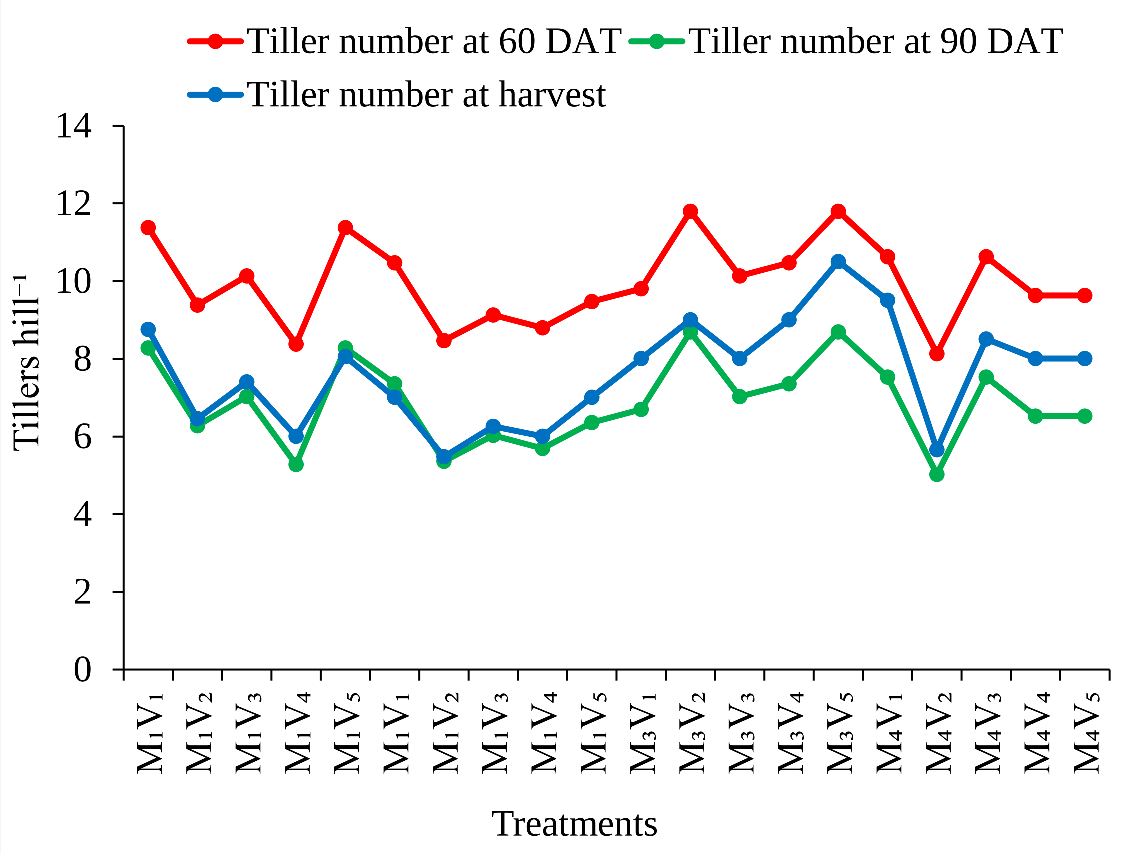

Figure 22. Interaction effect of micronutrients and variety on number of tillers hill^{-1} of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.3 Leaf length (cm) and leaf breadth (cm)

Interaction of micronutrients and variety exerted significant impact on leaf length of boro rice plants. Leaf length ranged from 27.83 cm (M_1V_3) to 41.87 cm (M_3V_1) where the shortest leaf was seen in control condition and the longest one from M_3V_1 treatment combination (Figure 23). At harvest stage, the impact of micronutrients and variety interaction on leaf breadth was significant (Figure 24). Leaf breadth ranged from 1.27 cm (M_2V_3) to 1.80 cm (M_4V_1).

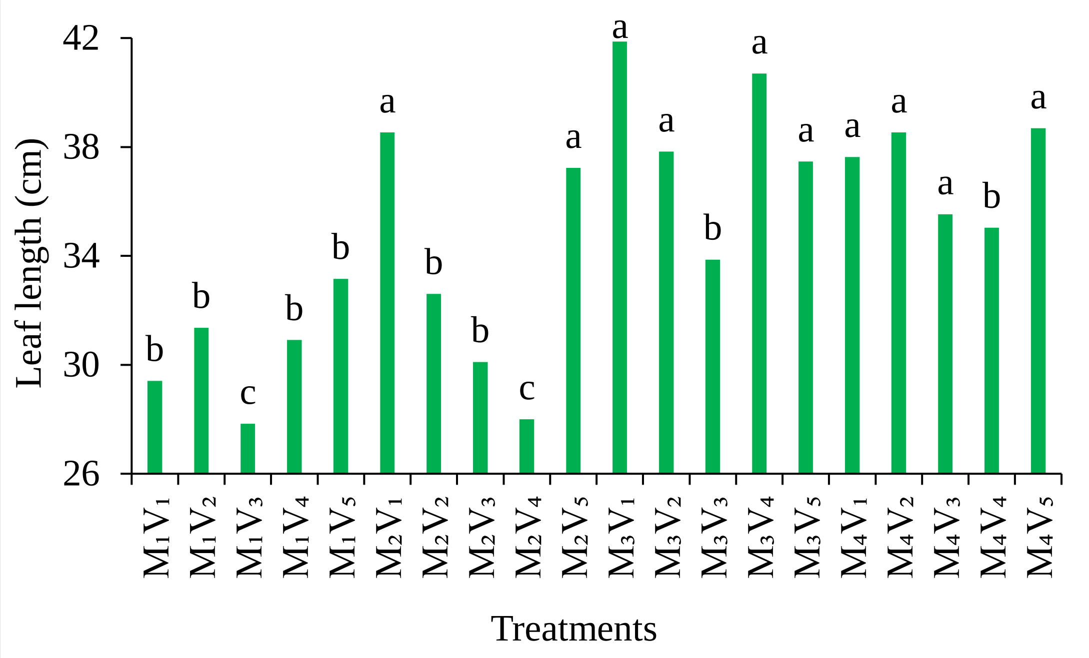

Figure 23. Interaction effect of micronutrients and variety on leaf length of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

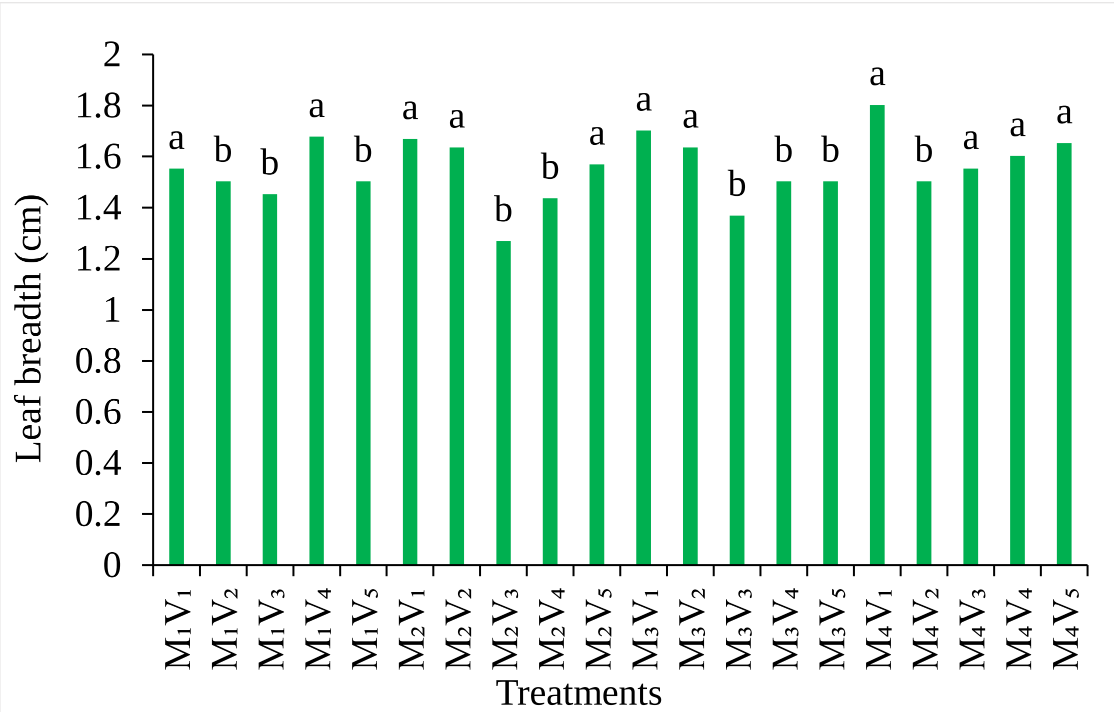

Figure 24. Interaction effect of micronutrients and variety on leaf breadth of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Filled grains panicle^{-1} of boro rice ranged from 17.62 (M_2V_2) to 99.62 (M_4V_5) which was significantly affected by interaction of micronutrients and variety (Figure 25). Rice varieties which were applied with micronutrients showed the maximum value for filled grains in compare to varieties without micronutrient application. Similarly, unfilled grains panicle^{-1} ranged from 5.60 (M_4V_1) to 35.36 (M_2V_3) (Figure 25) where micronutrient application exerted significant impact on rice varieties resulting in lower number of unfilled grains in compare to control condition in most of the cases.

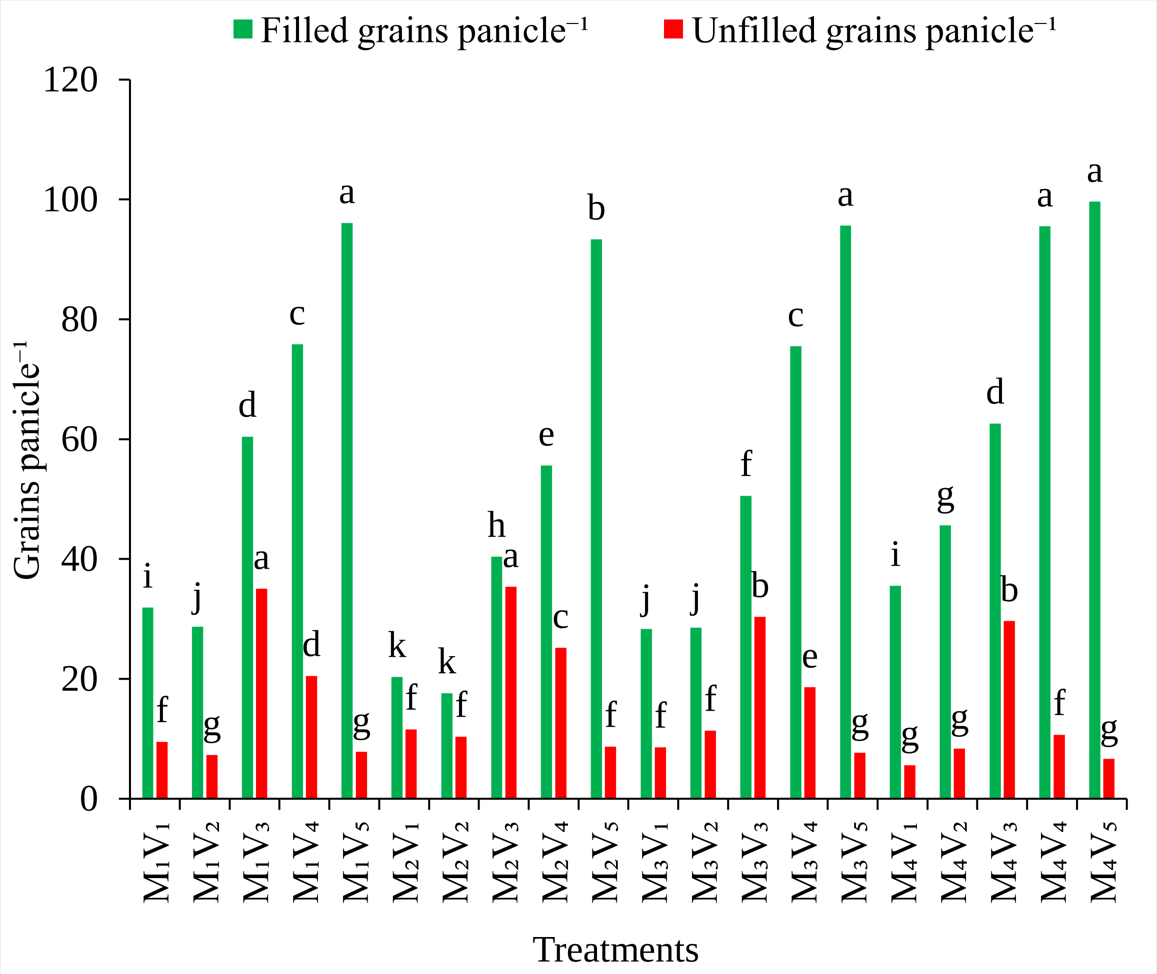

Figure 25. Interaction effect of micronutrients and variety on filled and unfilled grains panicle^{-1} of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.5 Panicle length

Interaction of micronutrients and variety exerted significant impact on panicle length of rice (Figure 26). Panicle length ranged from 12.51 cm (M_2V_4) to 24.46 cm (M_4V_5) where rice varieties under control condition had shorter panicle compare to varieties which were applied with micronutrients.

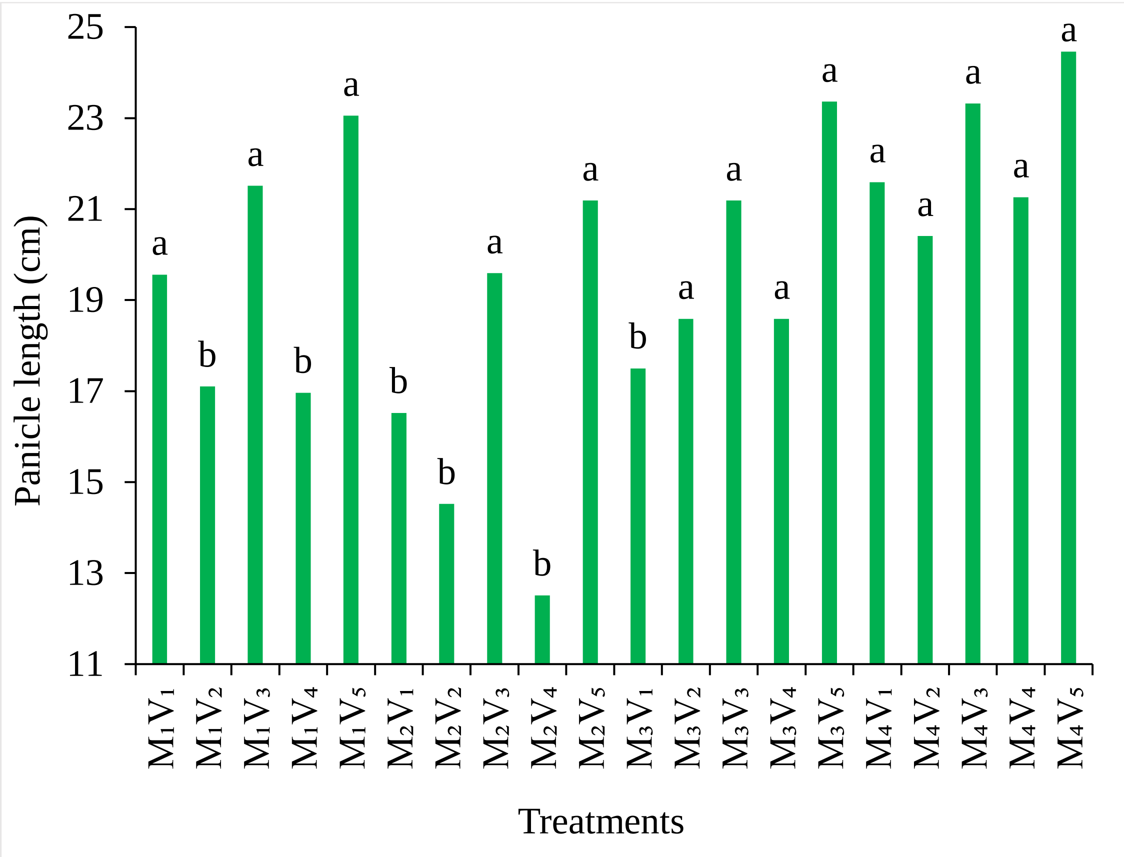

Figure 26. Interaction effect of micronutrients and variety on panicle length of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.6 Weight of 1000-grains (gm)

Interaction of micronutrients and variety exerted significant impact on weight of 1000-grains of rice (Figure 27). Weight of 1000-grains ranged from 11.84 g (M_2V_3) to 24.54 g (M_4V_5) where varieties under control condition had lower weight of 1000-grains of rice than varieties applied with micronutrients.

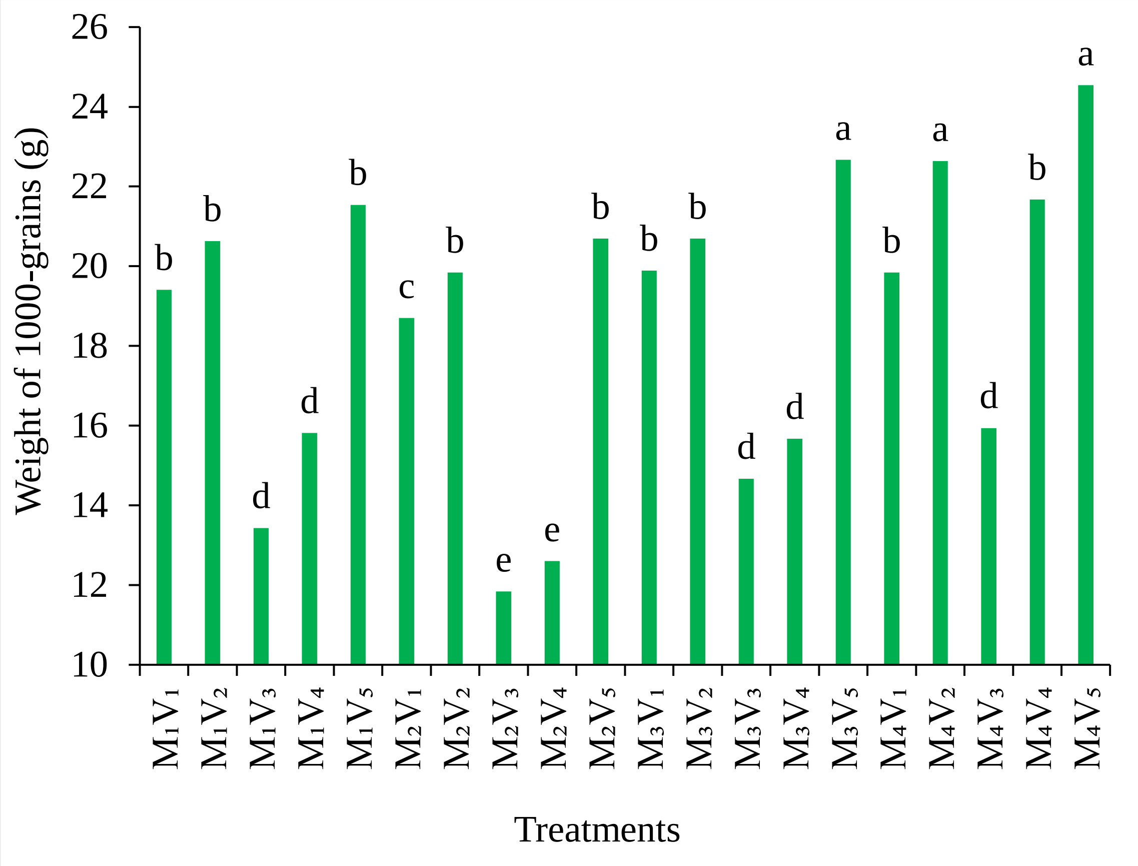

Figure 27. Interaction effect of micronutrients and variety on weight of 1000-grains of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.7 Grain yield

Interaction of micronutrients and variety exerted significant effect on grain yield of rice (Figure 28). Grain yield ranged from 19.78 g hill^{-1} (M_2V_4) to 30.86 g hill^{-1} (M_4V_3) where varieties under control condition had lower grain yield of rice than varieties applied with micronutrients. Combination of Boron and zinc showed higher grain yield of rice compared to individual application.

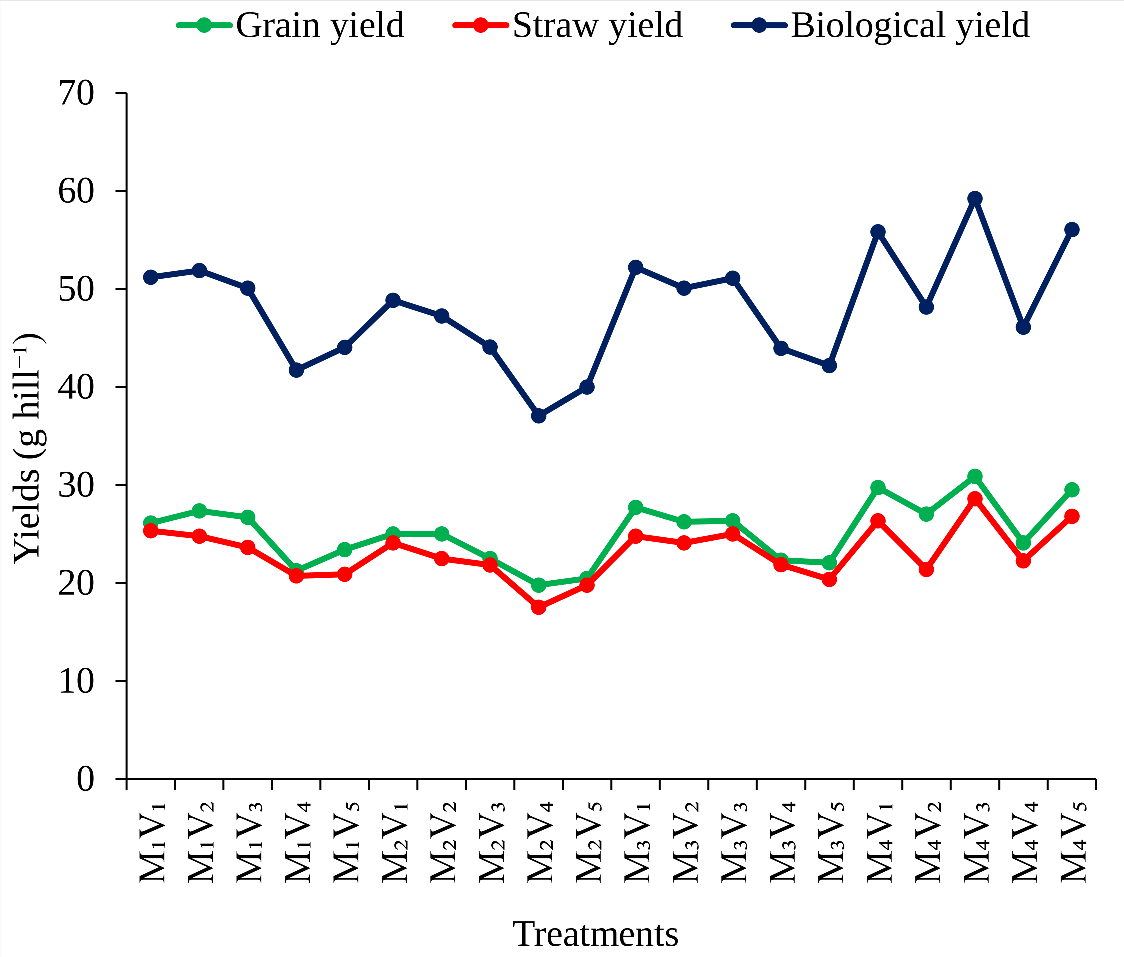

Figure 28. Interaction effect of micronutrients and variety on grain, straw and biological yields of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.8 Straw yield

Interaction of micronutrients and variety exerted significant effect on straw yield of rice (Figure 28). Straw yield ranged from 17.52 g hill^{-1} (M_2V_4) to 28.60 g hill^{-1} (M_4V_3) where varieties under control condition had lower straw yield of rice than varieties applied with micronutrient. Combination of Boron and zinc showed higher straw yield of rice compared to individual application.

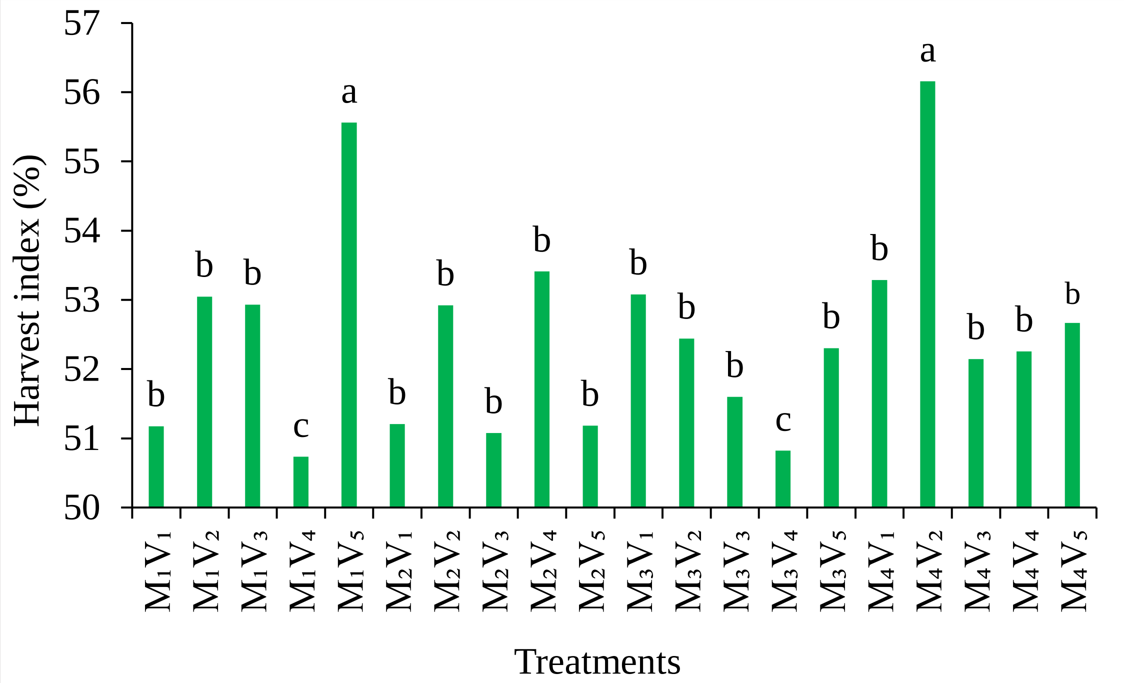

Figure 29. Interaction effect of micronutrients and variety on harvest index of boro rice. [M_1, M_2, M_3 and M_4 indicate control, Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment and significance of values were tested at $p \leq 0.05$ applying LSD test]

4.6.9 Biological yield

Interaction of micronutrients and variety exerted significant effect on biological yield of rice (Figure 28). Biological yield ranged from 37.06 g hill^{-1} (M_2V_4) to 59.22 g hill^{-1} (M_4V_3) where varieties under control condition had lower biological yield of rice than varieties applied with micronutrient. Combination of Boron and zinc showed higher biomass of rice compared to individual application.

4.6.10 Harvest index

Interaction of micronutrients and variety showed significant effect on harvest index of rice (Figure 29). Harvest index ranged from 50.73% (M_1V_4) to 56.16% (M_4V_2). Application of boron and zinc showed higher values of harvest index of rice compared to without micronutrient application.

4.7 Interaction effect of salinity, micronutrients and variety on growth, yield attributes, yield and harvest index of boro rice

4.7.1 Plant height

Plant height of rice varieties ranged from 41.23 cm to 60.51 cm at 60 DAT and 50.87 cm to 72.70 cm at 90 DAT with significant interaction effect of salinity stress, micronutrient levels and varieties of rice on it (Table 16). The tallest plant at 60 DAT (60.51 cm) was recorded from treatment combination $S_1M_1V_2$ which was 46.76% taller than the shortest one (41.23 cm) from $S_2M_1V_3$ treatment combination. At 90 DAT, the tallest plant (72.70 cm) was recorded from treatment combination $S_2M_3V_2$ which was 42.91% taller than the shortest one (50.87 cm) from $S_2M_2V_3$ treatment combination. There was significant ($P < 0.05$) difference in plant height due to interaction effect of salinity stress, micronutrient levels and varieties at harvest which ranged from 61.48 cm to 101.38 cm. At harvest, $S_1M_1V_2$ treatment showed the tallest plant (101.38 cm) which was statistically similar to $S_2M_3V_2$ and $S_2M_4V_2$ treatment combinations.

4.7.2 Number of tillers hill^{-1}

Combine treatment of salinity level, micronutrient level and variety had significant impact on number of tillers hill^{-1} at 60 and 90 DAT and at harvest (Table 17). At 60 DAT, tillers number of rice plants ranged from 7.63 to 12.13, where the maximum number of tillers hill^{-1} (12.13) was observed from $S_1M_1V_1$ treatment combinations. The minimum number of tillers hill^{-1} (7.63) at 60 DAT was recorded in $S_2M_1V_2$ combination. At 90 DAT, tillers number of rice plants ranged from 4.53 to 9.03, where the maximum number of tillers hill^{-1} (9.03) was observed from $S_1M_1V_1$ treatment which was statistically similar to $S_2M_3V_2$ and $S_2M_3V_5$ combinations. The minimum number of tillers hill^{-1} (4.53) at 90 DAT was recorded in $S_2M_1V_2$ combination. At harvest, tillers number of rice plants ranged from 4.51 to 10.51, where the maximum number of tillers hill^{-1} (10.51) was observed from $S_2M_3V_5$ treatment which was statistically similar to $S_1M_1V_1$ and $S_2M_3V_2$ combinations. The minimum number of tillers hill^{-1} (4.51) at harvest was recorded in $S_2M_1V_4$ combination which was 133.03% lower than the maximum one from $S_2M_3V_5$ combination.

Table 16. Interaction effect of salinity, micronutrients and variety on plant height at different growth stages of boro rice

Treatment combinations	Plant height (cm) at		
	60 DAT	**90 DAT**	**harvest**
$S_1M_1V_1$	51.33 bcd	61.27 h–k	91.94 a–e
$S_1M_1V_2$	60.51 a	70.37 ab	101.38 a
$S_1M_1V_3$	49.55 bcde	59.67 jkl	80.58 fgh
$S_1M_1V_4$	45.33 fghi	60.77 ijk	87.43 def
$S_1M_1V_5$	49.55 bcde	65.77 b–h	95.48 a–d
$S_2M_1V_1$	48.23 cdef	64.67 d–i	88.59 c–f
$S_2M_1V_2$	51.23 bcd	58.27 kl	79.68 f–i
$S_2M_1V_3$	41.23 j	51.27 mn	61.48 l
$S_2M_1V_4$	43.63 ghij	58.87 kl	69.74 h–l
$S_2M_1V_5$	42.13 hij	62.17 f–k	72.63 g–k
$S_2M_2V_1$	48.55 bcdef	66.43 b–f	89.68 b–f
$S_2M_2V_2$	52.55 b	62.40 f–k	97.62 a–d
$S_2M_2V_3$	41.33 ij	50.87 n	62.38 kl
$S_2M_2V_4$	45.33 fghi	52.17 mn	70.58 h–l
$S_2M_2V_5$	45.23 fghij	59.63 jkl	69.33 i–l
$S_2M_3V_1$	49.63 bcde	63.97 e–j	90.59 a–f
$S_2M_3V_2$	51.63 bc	72.70 a	99.40 abc
$S_2M_3V_3$	42.55 hij	52.27 mn	65.78 jkl
$S_2M_3V_4$	42.23 hij	55.93 lm	75.61 g–j
$S_2M_3V_5$	45.63 efgh	63.97 e–j	74.58 g–j
$S_2M_4V_1$	50.23 bcd	66.27 b–g	68.68 i–l
$S_2M_4V_2$	59.71 a	69.62 abc	100.36 ab
$S_2M_4V_3$	43.63 ghij	62.37 f–k	75.56 g–j
$S_2M_4V_4$	45.23 fghij	69.07 a–d	79.66 f–i
$S_2M_4V_5$	47.33 defg	68.27 a–e	81.98 efg
LSD $_{(.05)}$	**4.00**	**4.82**	**11.07**
CV (%)	**5.05**	**4.69**	**8.23**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.7.3 Leaf length and leaf breadth

Leaf length of rice plants was significantly influenced by combined treatment of salinity, micronutrients and variety (Table 18). Leaf length ranged from 26.18 cm to 41.87 cm among different combination of treatment. The longest leaf (41.87 cm) from $S_2M_3V_1$ treatment showed 56.34% lengthier leaf than $S_1M_1V_4$ treatment combination (26.18 cm).

Table 17. Interaction effect of salinity, micronutrients and variety on number of tillers hill^{-1} at different growth stages of boro rice

Treatment combinations	Number of tillers hill^{-1} at		
	60 DAT	90 DAT	harvest
$S_1M_1V_1$	12.13 a	9.03 a	10.51 a
$S_1M_1V_2$	11.13 c	8.03 abc	8.32 a–e
$S_1M_1V_3$	11.13 c	8.03 abc	8.56 a–d
$S_1M_1V_4$	8.63 ij	5.53 d–g	7.51 b–g
$S_1M_1V_5$	11.63 b	8.53 ab	9.11 abc
$S_2M_1V_1$	10.63 d	7.53 a–d	7.01 c–h
$S_2M_1V_2$	7.63 l	4.53 g	4.61 hi
$S_2M_1V_3$	9.13 h	6.03 b–g	6.26 d–i
$S_2M_1V_4$	8.13 k	5.03 fg	4.51 i
$S_2M_1V_5$	11.13 c	8.03 abc	7.01 c–h
$S_2M_2V_1$	10.47 d	7.36 a–e	7.01 c–h
$S_2M_2V_2$	8.47 j	5.36 efg	5.48 ghi
$S_2M_2V_3$	9.13 h	6.03 c–g	6.26 d–i
$S_2M_2V_4$	8.80 i	5.69 c–g	6.01 e–i
$S_2M_2V_5$	9.47 g	6.36 b–g	7.01 c–h
$S_2M_3V_1$	9.80 f	6.69 a–g	8.01 b–f
$S_2M_3V_2$	11.80 b	8.69 ab	9.01 abc
$S_2M_3V_3$	10.13 e	7.03 a–f	8.01 b–f
$S_2M_3V_4$	10.47 d	7.36 a–e	9.01 abc
$S_2M_3V_5$	11.80 b	8.69 ab	10.51 a
$S_2M_4V_1$	10.63 d	7.53 a–d	9.51 ab
$S_2M_4V_2$	8.13 k	5.03 fg	5.66 f–i
$S_2M_4V_3$	10.63 d	7.53 a–d	8.51 a–d
$S_2M_4V_4$	9.63 fg	6.53 a–g	8.01 b–f
$S_2M_4V_5$	9.63 fg	6.53 b–g	8.01 b–f
LSD (.05)	**0.26**	**2.16**	**2.42**
CV (%)	**1.55**	**18.87**	**19.25**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

Similarly, leaf breadth among different combination of treatment at harvest stage was also significant, which ranged from 1.27 cm to 1.80 cm. The widest leaf (1.80 cm) was recorded from $S_2M_4V_1$ combination while the narrowest leaf (1.27 cm) was observed in $S_2M_2V_3$ treatment.

Table 18. Interaction effect of salinity, micronutrients and variety on leaf length and breadth at harvest of boro rice

Treatment combinations	Leaf length at harvest (cm)	Leaf breadth at harvest (cm)
$S_1M_1V_1$	26.38 f	1.45 b–f
$S_1M_1V_2$	36.53 a–d	1.60 a–d
$S_1M_1V_3$	27.38 ef	1.60 a–d
$S_1M_1V_4$	26.78 f	1.65 abc
$S_1M_1V_5$	30.43 def	1.40 c–f
$S_2M_1V_1$	32.43 c–f	1.65 abc
$S_2M_1V_2$	26.18 f	1.40 c–f
$S_2M_1V_3$	28.28 ef	1.30 ef
$S_2M_1V_4$	35.03 bcd	1.70 ab
$S_2M_1V_5$	35.88 a–d	1.60 a–d
$S_2M_2V_1$	38.53 abc	1.67 ab
$S_2M_2V_2$	32.60 c–f	1.64 abc
$S_2M_2V_3$	30.10 def	1.27 f
$S_2M_2V_4$	28.00 ef	1.44 b–f
$S_2M_2V_5$	37.23 abc	1.57 a–d
$S_2M_3V_1$	41.87 a	1.70 ab
$S_2M_3V_2$	37.83 abc	1.64 abc
$S_2M_3V_3$	33.87 cde	1.37 def
$S_2M_3V_4$	40.70 ab	1.50 b–f
$S_2M_3V_5$	37.47 abc	1.50 b–f
$S_2M_4V_1$	37.63 abc	1.80 a
$S_2M_4V_2$	38.53 abc	1.50 b–f
$S_2M_4V_3$	35.53 a–d	1.55 a–e
$S_2M_4V_4$	35.03 bcd	1.60 a–d
$S_2M_4V_5$	38.68 abc	1.65 abc
LSD $_{(.05)}$	**6.50**	**0.26**
CV (%)	**11.55**	**9.94**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.7.4 Filled grains panicle^{-1} and Unfilled grains panicle^{-1}

Combination of treatments had significant effect on number of filled and unfilled grains panicle^{-1} of rice plants (Table 19). Number of filled grains per panicle ranged from 10.54 to 103.32. The maximum number of filled grains panicle^{-1} was observed from $S_1M_1V_4$ which was statistically similar to $S_1M_1V_5$ and $S_2M_4V_5$ combinations. The difference among the treatments regarding unfilled grains was also significant. Number of unfilled grains panicle^{-1} ranged from 2.36 to 41.43. $S_1M_1V_2$ treatment combination was recorded to produce the least number of unfilled grains (2.36) than other treatment, whereas, $S_2M_1V_3$ showed the greatest number of unfilled grains panicle^{-1} (41.43). Salinity stress combined with no micronutrient's application in BINA dhan8 variety tends to produce more unfilled grains among the different treatment combinations.

4.7.5 Panicle length

Panicle length of rice plants ranged from 10.52 cm ($S_2M_1V_4$) to 25.59 cm ($S_1M_1V_5$) with significant combined impact of salinity, micronutrients and variety on it (Table 19). Saline condition without micronutrients reduced length of panicle in compare to control condition.

4.7.6 Weight of 1000-grains

Combination of salinity, micronutrients and variety had significant effect on weight of 1000-grains of rice (Table 19). Weight of 1000-grains ranged from 8.09 g ($S_2M_1V_4$) to 24.54 g ($S_2M_4V_5$) where combined treatments with micronutrients showed heavier weight of 1000-grains than treatments with no micronutrients.

Table 19. Interaction effect of salinity, micronutrients and variety on yield contributing parameters of boro rice

Treatment combinations	Filled grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	Panicle length (cm)	Weight of 1000-grains (gm)
$S_1M_1V_1$	52.62 hi	3.38 mn	23.81 abc	20.27 cde
$S_1M_1V_2$	46.84 jk	2.36 n	21.51 a–d	22.67 abc
$S_1M_1V_3$	85.54 e	28.66 d	25.51 a	16.59 fg
$S_1M_1V_4$	103.32 a	7.66 jkl	23.41 abc	23.54 ab
$S_1M_1V_5$	101.62 a	5.36 lmn	25.59 a	23.34 ab
$S_2M_1V_1$	11.22 p	15.58 f	15.31 d–g	18.54 ef
$S_2M_1V_2$	10.54 p	12.26 g	12.69 fg	18.59 ef
$S_2M_1V_3$	35.32 m	41.43 a	17.51 c–f	10.27 ij
$S_2M_1V_4$	48.34 ijk	33.36 bc	10.52 g	8.09 j
$S_2M_1V_5$	90.54 d	10.26 g–j	20.51 a–e	19.74 de
$S_2M_2V_1$	20.34 o	11.56 gh	16.52 d–g	18.7 ef
$S_2M_2V_2$	17.62 o	10.36 g–j	14.52 efg	19.84 de
$S_2M_2V_3$	40.39 l	35.36 b	19.59 a–e	11.84 i
$S_2M_2V_4$	55.62 h	25.20 e	12.51 fg	12.60 hi
$S_2M_2V_5$	93.35 cd	8.68 h–k	21.19 a–d	20.69 cde
$S_2M_3V_1$	28.32 n	8.56 h–k	17.5 c–f	19.89 de
$S_2M_3V_2$	28.54 n	11.36 ghi	18.59 b–e	20.69 cde
$S_2M_3V_3$	50.54 ij	30.35 cd	21.19 a–e	14.67 gh
$S_2M_3V_4$	75.54 f	18.60 f	18.59 b–f	15.67 g
$S_2M_3V_5$	95.64 bc	7.68 jkl	23.36 abc	22.67 abc
$S_2M_4V_1$	35.54 m	5.60 klm	21.59 a–d	19.84 de
$S_2M_4V_2$	45.62 k	8.38 i–l	20.41 a–e	22.64 abc
$S_2M_4V_3$	62.62 g	29.66 d	23.32 abc	15.94 g
$S_2M_4V_4$	95.52 bc	10.66 g–j	21.26 a–d	21.67 bcd
$S_2M_4V_5$	99.62 ab	6.66 kl	24.46 ab	24.54 a
LSD (.05)	**4.64**	**3.15**	**6.72**	**2.56**
CV (%)	**4.89**	**12.22**	**20.63**	**8.32**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.7.7 Grain yield

Grain yield (g hill^{-1}) of rice plants was significantly influenced by interaction effect of salinity, micronutrients and variety (Table 20). Grain yield ranged from 15.71 g ($S_2M_1V_5$) to 32.90 g ($S_1M_1V_2$) where saline condition and no micronutrient application showed reduction in grain yield in compare to treatments with or without micronutrient application and no salinity.

Table 20. Interaction effect of salinity, micronutrients and variety on yield parameters and harvest index of boro rice

Treatment combinations	Grain yield ($g \cdot hill^{-1}$)	Straw yield ($g \cdot hill^{-1}$)	Biological yield ($g \cdot hill^{-1}$)	Harvest index (%)
$S_1M_1V_1$	31.77 ab	31.31 a	62.84 ab	50.58 fgh
$S_1M_1V_2$	32.90 a	30.86 ab	63.52 a	51.82 d–h
$S_1M_1V_3$	31.54 abc	24.98 a–f	56.28 a–d	56.07 b
$S_1M_1V_4$	26.56 a–f	25.03 a–f	51.35 cde	51.76 d–h
$S_1M_1V_5$	31.09 abc	31.54 a	62.38 ab	49.86 gh
$S_2M_1V_1$	20.46 efg	19.33 fgh	39.54 ghi	51.77 d–h
$S_2M_1V_2$	21.81 d–g	18.65 fgh	40.22 f–i	54.27 bc
$S_2M_1V_3$	21.81 d–g	22.27 c–h	43.84 e–h	49.79 h
$S_2M_1V_4$	15.93 g	16.39 hi	32.08 ij	49.70 h
$S_2M_1V_5$	15.71 g	10.19 i	25.65 j	61.26 a
$S_2M_2V_1$	24.98 b–f	24.08 b–g	48.81 c–g	51.21 d–h
$S_2M_2V_2$	24.98 b–f	22.49 c–h	47.23 d–h	52.92 c–f
$S_2M_2V_3$	22.49 d–g	21.81 c–h	44.07 e–h	51.08 d–h
$S_2M_2V_4$	19.78 fg	17.52 gh	37.06 hi	53.41 cd
$S_2M_2V_5$	20.46 efg	19.78 e–h	40.00 ghi	51.18 d–h
$S_2M_3V_1$	27.70 a–d	24.76 a–f	52.21 b–e	53.08 cde
$S_2M_3V_2$	26.25 a–f	24.08 b–g	50.08 c–g	52.44 c–f
$S_2M_3V_3$	26.34 a–f	24.98 a–f	51.08 c–f	51.60 d–h
$S_2M_3V_4$	22.31 d–g	21.86 c–h	43.93 e–h	50.82 e–h
$S_2M_3V_5$	22.04 d–g	20.37 d–h	42.17 e–i	52.30 c–f
$S_2M_4V_1$	29.73 abc	26.34 a–e	55.83 a–d	53.29 cd
$S_2M_4V_2$	27.02 a–e	21.36 d–h	48.14 d–g	56.16 b
$S_2M_4V_3$	30.86 abc	28.60 abc	59.22 abc	52.15 c–g
$S_2M_4V_4$	24.08 c–f	22.27 c–h	46.10 d–h	52.26 c–f
$S_2M_4V_5$	29.51 abc	26.79 a–d	56.06 a–d	52.67 c–f
LSD (.05)	**6.90**	**6.90**	**10.88**	**2.34**
CV (%)	**16.56**	**18.01**	**13.67**	**2.69**

[S_1 and S_2 indicate control and 150 mM NaCl, respectively. M_1, M_2, M_3 and M_4 indicate control (No micronutrients), Zn (0.5%), B (0.5%) and Zn + B (0.5%), respectively. V_1, V_2, V_3, V_4 and V_5 indicate BINA dhan10, BINA dhan8, BRRI dhan29, BRRI dhan47 and BRRI dhan67, respectively. Mean was calculated from three replicates for each treatment. Values in a column with different letters are significantly different at $p \leq 0.05$ applying LSD test]

4.7.8 Straw yield

Straw yield (g $hill^{-1}$**)** of rice plants was significantly affected by interaction effect of salinity, micronutrients and variety (Table 20). Straw yield ranged from 10.19 g ($S_2M_1V_5$) to 31.54 g ($S_1M_1V_5$) where salinity stress and no micronutrient application showed reduction in straw yield in compare to treatments with or without micronutrient application and no salinity.

4.7.9 Biological yield

Biological yield (g $hill^{-1}$) of rice plants was significantly influenced by interaction effect of salinity, micronutrients and variety (Table 20). Biological yield ranged from 25.65 g ($S_2M_1V_5$) to 63.52 g ($S_1M_1V_2$) where salinity stress and no micronutrient application showed reduction in biological yield in compare to treatments with or without micronutrient application and no salinity.

4.7.10 Harvest index

Harvest index (%) of rice plants was significantly affected due to combination of salinity, micronutrients and variety (Table 20). Harvest index ranged from 49.70% ($S_2M_1V_4$) to 61.26% ($S_2M_1V_5$) among the treatments.

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at net house of the department of agronomy, Sher-e-Bangla Agricultural University during the period from November, 2019 to March, 2020 to evaluate the effect of foliar application of micronutrients for increasing salinity tolerance in rice plants. The experiment consisted of three factors. The factors were: factor A: Salinity level (2): S_1 = Control (No saline water) and S_2 = 150 mM NaCl; factor B: Micronutrients (4): M_1 = Control (No micronutrients), M_2 = Zinc (0.5%), M_3 = Boron (0.5%) and M_4 = Zinc (0.5%) + Boron (0.5%); factor C: Variety (5): V_1 = BINA dhan10, V_2 = BINA dhan8, V_3 = BRRI dhan29, V_4 = BRRI dhan47 and V_5 = BRRI dhan67. The experiment was laid out in a RCBD factorial design with three (3) replications. Total 120 unit-pots were prepared for the experiment. Each pot was of required size. Data on different growth, yield contributing and yield parameter of rice were recorded and significant variation was recorded for different treatments.

It was observed that the control plants S_1 (No saline water) out-yielded by producing 58.23% higher grain yield over S_2 (150 mM NaCl). The treatment S_1 (No saline water) also showed the tallest plant at harvest (91.36 cm), highest number of tillers hill^{-1} (8.80), longest leaf at harvest (36.07 cm), widest leaf at harvest (1.74 cm), longest panicle length (25.97 cm), highest number of filled grains panicle^{-1} (77.99), lowest number of unfilled grains panicle^{-1} (9.48), maximum weight of 1000-grains (21.28 g), straw yield (28.75 g hill^{-1}), biological yield (61.52 g hill^{-1}) and harvest index (53.26%) in compare to salinity stress-imposed plants.

Significant differences existed among different levels of micronutrient applications with respect to yield and yield attributing parameters. A yield advantages of 5.28 g, 5.31 g and 10.94 g hill^{-1} over M_1 (No micronutrients), M_3 [B (0.5%)] and M_2 [Zn (0.5%)] applied pot, respectively was found which was possibly aided by taller plant (86.24 cm), higher number of tillers hill^{-1} (7.94), longer panicle (22.21 cm), maximum number of filled grains panicle^{-1} (67.79), lowest number of unfilled grains panicle^{-1} (12.19), highest weight of 1000-grains (20.93 g), straw yield (26.07 g hill^{-1}), biological yield (56.31 g hill^{-1}) and harvest index (53.70%) in the M_4 [Zn + B (0.5%)] treatment. On the other hand, treatment M_3 [B (0.5%)] gave similar results to M_4 treatment in some parameters like—plant height, tillers number, leaf length, number of unfilled grains panicle^{-1}, panicle length, weight of 1000-grains, straw yield, biological yield and harvest index.

The result revealed that V_5 (BRRI dhan67) exhibited its superiority to other tested variety BINA dhan10, BINA dhan8 and BRRI dhan29 in terms of seed yield, the former out-yielded over V_1 (BINA dhan10) by 13.34%, V_2 (BINA dhan8) by 1.27% and V_3 (BRRI dhan29) by 1.20 % higher yield. V_5 (BRRI dhan67) also showed the highest number of filled grains panicle^{-1} (96.16), lowest number of unfilled grains panicle^{-1} (7.72), highest weight of 1000-grains (22.20 g), maximum length of panicle (23.02 cm), higher biological yield hill^{-1} (45.18 g) and the highest harvest index (59.60%) compare to other tested varieties. On the other hand, the variety BRRI dhan29 returned with 37.18% lower grain yield which was significantly lower than BRRI dhan67 variety.

Interaction of salinity level and different micronutrient applications significantly influenced most of the studied parameters including grain yield. The interaction of S_1M_1 was recorded to have the highest grain yield (30.77 g hill^{-1}) than other interactions except S_2M_4 (28.24 g hill^{-1}) which may be attributed to the highest number of filled grains panicle^{-1} (77.99), lowest number of unfilled grains panicle^{-1} (9.48), maximum length of panicle (23.97 cm), maximum weight of 1000-grains (21.28 g) in this interaction. This interaction also showed the highest straw (28.75 g hill^{-1}) and biological yield (59.28 g hill^{-1}). However, interaction of S_2M_4 showed statistically similar grain yield and some yield attributes like—panicle length (22.21 cm), number of filled grains panicle^{-1} (67.79), number of unfilled grains panicle^{-1} (12.19) and weight of 1000-grains (20.93 g) to S_1M_1.

Interaction results of variety and salinity level indicated that most of the studied parameters were influenced significantly including grain yield. Significantly the highest grain yield (32.90 g $hill^{-1}$) was found in S_1V_2 (No saline water × BINA dhan8) interaction due to the tallest plant (101.38 cm), lowest number of unfilled grains $panicle^{-1}$ (2.36) and higher weight of 1000-grains (22.67 g) production. It was also observed that S_1V_1 showed the second highest grain yield (31.77 g $hill^{-1}$).

Interaction of micronutrient applications and variety exhibited significant variation in all the studied parameters in this experiment. The interaction M_4V_3 (Zn + B (0.5%) × BRRI dhan29) performed the best in respect of grain yield $hill^{-1}$ (30.86 g) which may be attributed to higher length of panicle (23.32 cm) production which also showed the highest straw yield (28.60 g $hill^{-1}$) and biological yield (59.22 g $hill^{-1}$) in this interaction.

Interaction effects of salinity level, micronutrient applications and variety showed significant variation for all the studied parameters. Among the interactions, $S_1M_1V_2$ was superior in producing the highest grain yield (32.90 g $hill^{-1}$) along with the tallest plant at harvest (101.38 cm), lowest number of unfilled grains $panicle^{-1}$ (2.36), higher length of panicle (21.51 cm), higher weight of 1000-grains (22.67 g), straw yield (30.86 g $hill^{-1}$) and the highest biological yield (63.52 g $hill^{-1}$). $S_2M_4V_5$, $S_2M_3V_1$, $S_2M_3V_2$, $S_2M_3V_3$ and $S_2M_4V_2$ interaction showed statistically similar grain yield $hill^{-1}$ to $S_1M_1V_2$ interactions.

CONCLUSION

From the above result it was revealed that S_1 (No saline water), M_4 [Zn + B (0.5%)] and V_5 (BRRI dhan67) gave higher yield along with higher values in most of the yield attributing parameters. Among the interactions; S_1M_1, S_1V_2 and M_4V_3 were superior in most of the studied parameters along with grain yield.

Interaction of $S_1M_1V_2$ (No saline water × No micronutrients × BINA dhan8) performed better in most of the studied parameters. The $S_1M_1V_2$ treatment combination also showed better performance in terms of grain yield. From the result of the experiment, it may be concluded that application of Zinc (0.5%) + Boron (0.5%) combinedly seems promising in mitigating salinity stress in rice field compared to individual application of zinc or boron.

RECOMMENDATION

Considering the results of the present experiment, further studies in the following areas are suggested:

1. More micronutrients with different levels may be used for combating saline water/salinity stress in boro rice.
2. Studies of similar nature could be carried out in different agro-ecological zones (AEZ) of Bangladesh for the evaluation of zonal adaptability.

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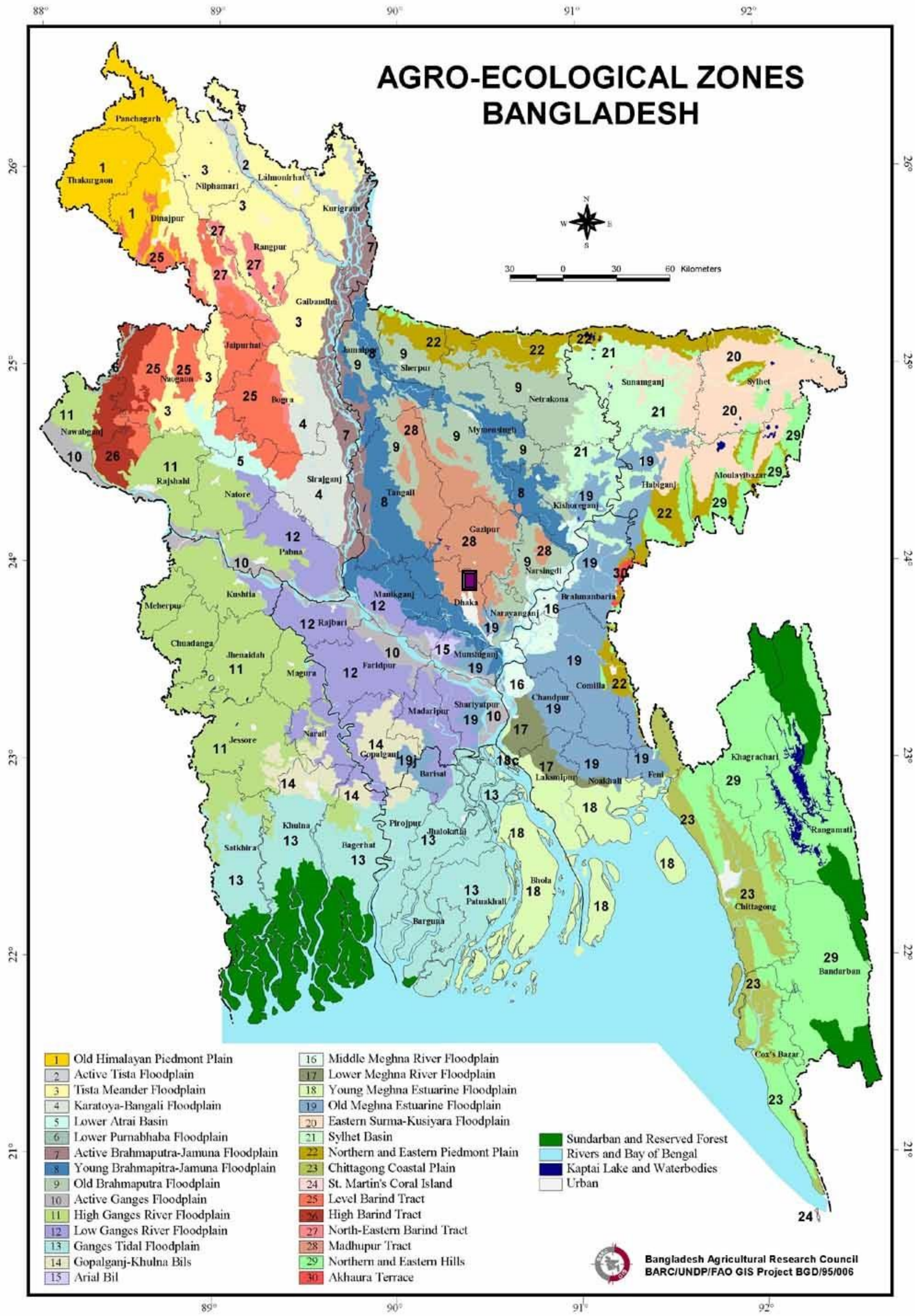
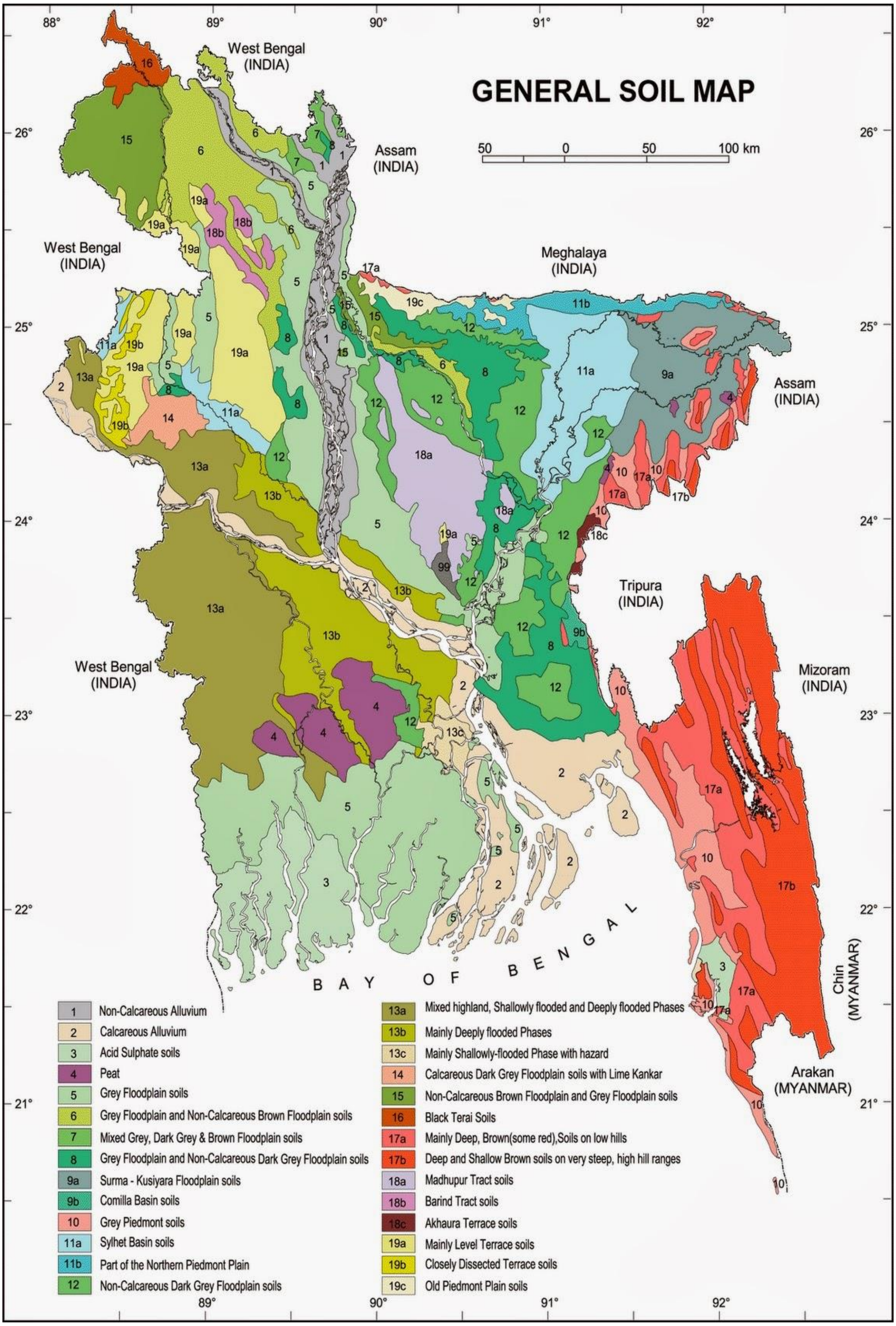
APPENDICES

Appendix I (A). Map showing the experimental sites under study



The experimental site under study

Appendix I(B). Map showing the general soil sites under study



Appendix II. Characteristics of soil of experimental site is analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping Pattern	Boro–Aman–Boro

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.5
Organic carbon (%)	0.43
Organic matter (%)	0.75
Total N (%)	0.075
Available P (ppm)	21.00
Exchangeable K (meq/ 100 g soil)	0.11
Available S (ppm)	43

Source: SRDI, 2019

Appendix III. Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from November 2019 to March 2020

Year	Month	Temperature			Relative Humidity (%)	Rainfall (mm)	Sunshine (Hour)
		Max (°C)	Min (°C)	Mean (°C)			
2019	November	32	24	29	65	42.8	349
	December	27	19	24	53	1.4	372
2020	January	27	18	23	50	3.9	364
	February	30	19	26	38	3.1	340
	March	35	24	31	38	19.6	353

Appendix IV. Analysis of variance (mean square) of plant height of boro rice

Source of variation	Degrees of freedom	Mean Square value of		
		Plant height at 60 DAT	Plant height at 90 DAT	Plant height at harvest
Salinity	1	144.672*	30.125*	1203.302*
Micronutrients	3	57.0199*	403.701*	130.403*
Variety	4	334.739*	315.072*	1514.593*
Salinity × Micronutrients	3	13.955*	−157.853*	268.247*
Salinity × Variety	4	−175.462*	−183.093*	−976.587*
Micronutrients × Variety	12	84.14004*	155.497*	725.009*
Salinity × Micronutrients × Variety	12	−11.5906*	−37.594*	−190.143*
Error	35	5.817618	8.455	44.641
Total	74	27.95839	40.626	169.353

* indicates significant at 5% level of probability

Appendix V. Analysis of variance (mean square) of tiller no. of boro rice

Source of variation	Degrees of freedom	Mean Square value of		
		Tiller no. at 60 DAT	Tiller no. at 90 DAT	Tiller no. at harvest
Salinity	1	9.92*	9.919*	17.580*
Micronutrients	3	12.66*	12.656*	34.460*
Variety	4	8.05*	8.055*	9.409*
Salinity × Micronutrients	3	−3.14*	−3.144*	−1.396*
Salinity × Variety	4	−1.26*	−1.258*	−3.849*
Micronutrients × Variety	12	5.75*	5.746*	6.376*
Salinity × Micronutrients × Variety	12	−1.33*	−1.333*	−1.951*
Error	35	0.0241	1.698	2.126
Total	74	1.613	2.406	3.602

* indicates significant at 5% level of probability

Appendix VI. Analysis of variance (mean square) of leaf length and breadth of boro rice

Source of variation	Degrees of freedom	Mean Square value of	
		Leaf length at harvest	Leaf breadth at harvest
Salinity	1	232.548*	0.001*
Micronutrients	3	382.661*	0.066*
Variety	4	57.518*	0.110*
Salinity × Micronutrients	3	−184.935*	−0.032*
Salinity × Variety	4	13.727*	−0.032*
Micronutrients × Variety	12	55.104*	0.093*
Salinity × Micronutrients × Variety	12	−10.012*	−0.020*
Error	35	15.370	0.024
Total	74	29.592	0.029

* indicates significant at 5% level of probability

Appendix VII. Analysis of variance (mean square) of yield contributing characters of boro rice

Source of variation	**Degrees of freedom**	**Mean Square value of**			
		Filled grains panicle^{-1}	**Unfilled grains panicle^{-1}**	**Panicle length**	**Weight of 1000 grains**
Salinity	1	5050.13*	432.52*	219.43*	88.03*
Micronutrients	3	2535.01*	187.11*	143.32*	90.91*
Variety	4	12653.16*	1758.24*	94.39 *	174.50*
Salinity × Micronutrients	3	823.52*	192.30*	42.60*	23.31*
Salinity × Variety	4	−7781.56*	−1040.18*	−62.77*	−105.19*
Micronutrients × Variety	12	2773.81*	344.06*	25.08*	44.98*
Salinity × Micronutrients × Variety	12	72.64*	53.34*	3.73*	9.83*
Error	35	7.82	3.61	16.419	2.38
Total	74	933.02	126.19	24.6504107	19.58

* indicates significant at 5% level of probability

Appendix VIII. Analysis of variance (mean square) of yield characters of boro rice

Source of variation	Degrees of freedom	Mean Square value of			
		Grain yield hill^{-1}	Straw yield hill^{-1}	Biological yield hill^{-1}	Harvest index
Salinity	1	373.777	372.820	1493.193	3.115*
Micronutrients	3	164.446 *	77.578 *	466.077*	11.774*
Variety	4	78.639 *	54.404*	258.401*	11.901*
Salinity × Micronutrients	3	131.288*	160.835*	593.001*	−2.326*
Salinity × Variety	4	−44.340*	−2.927*	−112.168*	11.641*
Micronutrients × Variety	12	26.895*	31.551*	108.931*	12.781*
Salinity × Micronutrients × Variety	12	−2.829*	3.688*	0.255*	12.884*
Error	35	17.311	17.311	43.059	1.990
Total	74	30.985	31.388	109.090	6.801

* indicates significant at 5% level of probability