EXOGENOUS APPLICATION OF SALICYLIC ACID ON MITIGATION OF DROUGHT STRESS OF BRRI DHAN28

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June, 2018

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A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka,
In partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE
IN
AGRICULTURAL BOTANY

SEMESTER: JANUARY-JUNE, 2018

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CERTIFICATE

This is to certify that the thesis entitled, " ***EXOGENOUS APPLICATION OF SALICYLIC ACID ON MITIGATION OF DROUGHT STRESS OF BRRI DHAN28"*** *submitted to the Department of Agricultural Botany, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE in AGRICULTURAL BOTANY,*** *embodies the results of a piece of bonafide research work carried out by* ***MST. MARGINA KHATUN*** *Registration No.* ***12-04892*** *under my supervision and my 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: June, 2018
Place: Dhaka, Bangladesh

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ACKNOWLEDGEMENTS

All praises goes to Almighty Allah, the Supreme Ruler of the universe who enabled the Author to complete the present piece of work.

I would like to express my heartiest respect, my deep sense of gratitude and sincere, profound appreciation to my supervisor, ***Md. Tofail Hosain, Assistant Professor*** *Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka for his sincere guidance, scholastic supervision, constructive criticism and constant inspiration throughout the course and in preparation of the manuscript of the thesis.*

I would like to express my heartiest respect and profound appreciation to my Co-supervisor, ***Prof. Dr. Md. Moinul Hoque****, Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka for his utmost cooperation and constructive suggestions to conduct the research work as well as preparation of the thesis.*

I express my sincere respect to the Chairman, ***Dr. Kamrun Nahar, Associate Professor*** *and all the teachers of Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka for providing the facilities to conduct the experiment and for their valuable advice and sympathetic consideration in connection with the study.*

I would like to thank my entire roommates and friends especially senior brother to help me in my research work.

Mere diction is not enough to express my profound gratitude and deepest appreciation to my father, mother, brothers, sisters, and friends for their ever ending prayer, encouragement, sacrifice and dedicated efforts to educate me to this level.

Dated: June, 2018 ***The Author***
Place: SAU, Dhaka

EXOGENOUS APPLICATION OF SALICYLIC ACID ON MITIGATION OF DROUGHT STRESS OF BRRI DHAN28

ABSTRACT

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2017 to May, 2018 to know the effect of foliar application of salicylic acid on mitigation of drought stress of BRRI dhan28. the experiment consist of two factors with different levels of treatments viz A: T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA. B: different level of drought stress, S_0 = control (normal irrigation), S_1 = moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from panicle initiation stage to season end). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Significant variation was recorded for data on growth, yield and yield contributing parameters. The maximum values for plant height, number of leaves hill^{-1}, number of tillers hill^{-1}, dry weight hill^{-1}, leaf area index, relative water content (%), leaf membrane stability index, flag leaf chlorophyll content (μMm^{-2}), thousand seed weight, number of filled grains panicle^{-1}, 1000 grain weight (g), grain yield, and straw yield, biological yield, harvest index were obtained from foliar application of SA @ 750 μMm^{-2}). Significant influence was remarked in terms of all parameter with different level of drought stress of *BRRI dhan28*. Results showed that the highest plant height, number of leaves hill^{-1}, number of tillers hill^{-1}, root dry weight plant^{-1}, dry weight plant^{-1}, leaf area index, relative water content, leaf membrane stability index, flag leaf chlorophyll content, number of filled grains panicle^{-1} was also obtained from normal irrigation without drought stress. The maximum grain yield was obtained from normal irrigation. The treatment normal irrigation produced the highest straw yield, biological yield and harvest index. Interaction effect of salicylic acid and different level of drought stress was significantly influenced for all parameter measured. The maximum grain yield (12.02 g hill^{-1}) was with foliar application of SA @ 750μMm^{-2} with normal irrigation. BRRI dhan 28 planted with drought stress at panicle initiation stage (severe drought stress) would be mitigated by the application of SA @ 750μMm^{-2}.

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LIST OF ABBREVIATION AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
HRC	=	Horticulture Research Centre
BBS	=	Bangladesh Bureau of Statistics
FAO	=	Food and Agricultural Organization
et al.	=	And others
TSP	=	Triple Super Phosphate
MOP	=	Muriate of Potash
RCBD	=	Randomized Complete Block Design
DAT	=	Days after Transplanting
ha^{-1}	=	Per hectare
g	=	gram (s)
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources and Development Institute
wt	=	Weight
LSD	=	Least Significant Difference
^{0}C	=	Degree Celsius
NS	=	Not significant
%	=	Percent
NPK	=	Nitrogen, Phosphorus and Potassium
CV%	=	Percentage of Coefficient of Variance

CHAPTER

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal crop in the world and it is the staple food for nearly half of the world's population as well as for 144.043 million people of Bangladesh (AIS, 2016). About 75% of the annual rice supply comes from 79 million hectares of irrigated paddy land in Bangladesh. The total world production is about 738.1 million tones in nearly 162.3 million hectares land (FAO, 2014). Based on rice cultivation, Bangladesh is the 4th largest country in the world (BBS, 2012). The population of Bangladesh is growing by two million every year and may increase by another 30 million over the next 20 years. Thus, Bangladesh will require about 27.3 million tons of rice for the year 2020 (BRRI, 2016). During this time total rice cultivating area will also shrink to 10.3 million hectares. Rice yield therefore, needs to be increased by 53.3% (Mahamud *et al*., 2013). Our country, food security has been and will remain a major concern because food requirement is increasing at an alarming rate due to increasing population. Rice yield, in general, is comparatively lower than that of other Southeast Asian countries because of the severe insect infestation, drought, salinity etc. To feed the ever increasing population of Bangladesh rice production must be increased either by horizontal expansion of cultivable land or by vertical expansion of production per unit area. However, expansion of cultivable lands in our densely populated country is quite difficult. For this reason our rice must be increased by vertical expansion of per unit area productivity. The productivity of a crop may be interrupted or reduced by lack of proper surrounding environment factors.

Rice holds a strong position in our cropping systems. Our cropping systems are mostly rice based throughout the country. There are three seasons of rice; *aus*, *aman* and *boro*. Rice grown in summer is called *aus*, while those planted in winter are boro. Rice planted in the rainy portion of summer and harvested in winter called *aman* (BRRI, 2013). Rice is grown both under irrigated and rain-fed condition in Bangladesh. Rain-fed *aus* rice suffers from drought stress at the early part of crop growth when there is a shortfall of rain. *Boro* rice is grown under irrigated condition and this crop has been extensive especially after the onset of development of irrigation system in Bangladesh after eighties. Due to high and availability of irrigation, *boro* cultivation extended even in the fields of pulses and oilseed crops in Bangladesh. Owing to the longer duration of the *boro* crops, area under *aus* rice production has reduced significantly. As a result we have to depend largely for food requirements on *boro* and *aman*. The past years have seen a growing scarcity of water worldwide. The pressure to reduce water use in irrigated agriculture is mounting, especially in Asia where it accounts for 90% of total diverted fresh water. Rice is an obvious target for water conservation: it is grown on more than 30% of irrigated land and accounts for 50% of irrigation water (Barker *et al*., 1999).

Salicylic acid (SA), a phenolic compound, is associated with stress tolerance in plants. Several reseacher reported that SA can induce tolerance against abiotic and biotic stress including high and low temperatures, drought, salinity, ultraviolet light, heavy metal toxicity, diseases and pathogens (Raskin, 1992; Yalpani *et al*., 1994; Dat *et al*., 1998; Metwally *et al.*, 2003; Sakhabutdinova *et al*., 2003; Hayat and Ahmad, 2007; Horváth *et al*., 2007, Farooq *et al.*, 2008; Hussain *et al*., 2008). In addition, SA plays an essential role in preventing oxidative damage in plants by detoxifying superoxide radicals (Bowler et *al*., 1992) and is also involved in calcium signaling (Kawano *et al*., 1998). Plants treated with SA showed increased vigor of early seedling growth (Farooq *et al*., 2008), increased photosynthetic rates, induced stomatal closure, increased water use efficiency, and decreased stomatal conductance and transpiration rate (Khan *et al*., 2010; Issak *et al*., 2013). Moreover, there is evidence that exogenous application of SA can alter antioxidant capacity in plants (Rao *et al*., 1997), thereby providing protection against oxidative damage (Larkindale and Huang 2004), and inducing stress tolerance.

Salicylic acid is the first plant derivative phenolic compound to induce systemic acquired resistance (Araujo *et al*., 2005). It is involved in a variety of physiological processes, and is included in a new class of plant growth regulating substances. This compound is found in leaves, inflorescences of thermo genic plants, and in plants attacked by pathogens (Castro and Vieira, 2001). A detailed analysis on 34 species considered significant for agriculture, such as Rice, Soybean, and Barley, has confirmed the distribution of salicylic acid at levels above 1μg.g^{-1} of fresh material such as in leaves and reproductive structures (Raskin *et al*., 1990).

The adverse effects of drought are significant in agriculture. Degradation of productive land including quality and physical losses are key concern for agriculture due to drought. In Bangladesh, plant suffer drought from March to May which is the reproductive stage of *boro* rice. Salicylic acid is a phenolic compound having ability of antioxidant defense system that regulates various physiological and biochemical processes in plant. Salicylic acid has a key role in tolerance of abiotic stress such as drought tolerance in maize, wheat, sunflower and barley. Salicylic acid mitigates harmful effect of drought stress due to its role in photosynthesis and in stomatal regulation. However, research work on mitigation of drought stress in rice crops by salicylic acid is scanty in Bangladesh. With conceiving the above scheme in mind, the present research work has been undertaken in order to fulfilling the following objectives-

i. To evaluate the physiological and yield behavior of rice under drought stress using SA as foliar application

ii. To develop a possible strategy on mitigating drought stress in rice using SA.

CHAPTER II

REVIEW OF LITERATURE

Rice is the most important cereal crop in the world as well as Bangladesh. The crop received much attention to the researcher of different countries including Bangladesh. However a few investigations have been taken on mitigation of drought stress in rice by salicylic acid in Bangladesh. There is a little or no combined research work to the yield performance of rice following the application of SA. The literature and research results related to the present study are reviewed in this chapter.

2.1 Drought susceptibility of rice plants

2.1.1 Effect of Plant height

Ramakrishnaya and Murty (1991) found that soil moisture stress reduced plant height and tiller number.

Islam and Gretzmacher (2001) observed in their experiments that plant height was decreased by the water stress at booting stage only.

De Datta (1981) stated that generally, continuous hooding in nee at 15 cm or more has the potential to produce yields similar to those at 2.5 cm water depth. However, in some dry seasons at 15 cm depth or more may reduce grain yield. Plant height will increase substantially and tiller number will decrease at a water depth of 15 cm or more.

Severe water stress may result in the arrest of photosynthesis, disturbance in metabolism and finally the death of plant (Jaleel *et al*., 2008). It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates and nutrient metabolism and growth promoters.

According to (DOASL, 2006), stress has been defined as “any environmental factor capable of inducing a potentially injurious strain in plants. Water is a major constituent of tissue, a reagent in chemical reaction, a solvent for and mode of translocation for metabolites and minerals within plant and is essential for cell enlargement through increasing turgor pressure. With the occurrence of water deficits many of the physiological processes associated with growth are affected and under severe deficits, death of plants may result.

Chauhan *el al*. (1999) found in a field trial that two nee varieties Browngara and Vandana were subjected to water stress at booting or anthesis stage water stress at both stages reduced plant height, total dry matter tiller^{-1} and panicle weight yield reduction due to moisture stress at booting stage was 72.5 % in Vandana and 93.9 % in Browngoga. While it was 54.5 % in Vandana and 74.7 % in Browngora due to stress at anthesis.

Several researchers reported that (Farooq, *et al*., 2008, Jaleel, *et al*., 2008b and Razmjoo *et al*., 2008) abiotic stress is a limiting factor in agriculture production by preventing a crop from reaching the genetically determined theoretical maximum yield (Begg and Turner, 1976). In plants, a better understanding of the morphological and physiological basis of changes in water stress resistance could be used to select or create new varieties of crops to obtain a better productivity under water stress conditions (Nam, *et al*., 2001 and Martinez, *et al*., 2007). The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity, duration of stress, plant species and its growth stages (Chaves, *et al*., 2002; Jaleel, *et al*., 2008c).

Rahman and Yoshida (1985) stated that water stress had little effect on grain filling stage. Water stress reduced the plant height increased percentage of sterile spikelet's, root dry matter yield, root- shoot ratio and growth duration of upland rice. There was no significant effect on that of lowland cultivars (Stone *et al*; 1984).

2.1.2 Effect of number of tillers hill^{-1}

Polon *et al.,* (1995) showed that acute water stress for 15-25 days decreased grain yield by >2.3 t ha^{-1}. When water supply was restored, higher rates of tillering was observed and increased number of panicles m^{-1}

Dawood *et al.* (1990) found that the number of productive tillers hill^{-1}, were significant influenced by irrigation levels irrigation increased number of tillers, number of effective tillers. Moisture stress at different growth stages reacted differently. Murty (1987) found that moisture stress at tillering stage reduced tiller production and grain yield. Kobata and lakami (1983) reported that stressed plants showed 40% reduction in dry matter production.

2.1.3 Effect of dry mater production of rice

Borrell *et al*., (1997) studied the effects of seasonal irrigation method on the functional component of rice yield the irrigation treatments were flooded from sowing to harvest, permanent flood from three-leaf stage to harvest, permanent flood from panicle initiation to harvest, saturated soil cultured and intermittent irrigation. Results showed that dry matter production increased with water supply but there were no significant differences in yield between the saturation soil culture and permanent flood from three leaf stage to harvest.

Islam and Gretzmacher (2001) observed in their experiments that plant height and length of panicle were decreased by the water stress at booting stage only. Stress at booting stage affected more than that of flowering in total dry matter production.

Rahman and Yoshida (1985) stated that water stress had little effect on grain tilling stage. Water stress reduced the total dry matter (TDM) and increased percentage of sterile spikelet's, root dry matter, root- shoot ratio and growth duration of upland rice. There was no significant effect on that of lowland cultivars (Stone *el al*., 1984)

Drought stress is characterized by reduction of water content diminished leaf water potential, turgor pressure, stomata activity and decreasement in cell enlargement and growth. Drought stress tolerance is seen in almost all plants but its extent varies from species to species, even within the species. Water deficit and salt stresses are global issues to ensure survival of agricultural crops and sustainable food production (Jaleel, *et al*., 2007). Conventional plant breeding attempts changed over to use physiological selection criteria since they are time consuming and rely on present genetic variability (Zhu, 2002).

Drought stress is considered to be a loss of water, which leads to stomatal closure and limitation of gas exchange. Drought stress in rice affects the crop in different ways. According to Tao *et al.* (2006) rice is the most unproductive crop in terms of water loss. On average, about 2,500 liters of water need to be supplied (by rainfall and/or irrigation) to a rice field to produce 1 kg of rough rice. These 2,500 liters account for all the outflows of water through evapotranspiration, seepage, and percolation (Bouman and Toung, 2001).

Drought stress is a major constraint for about 50% of the world production area of rice. Yield losses from drought in lowland rice can occur when soil water contents drop below saturation (Bouman and Toung, 2001). Rice crops are susceptible to drought, which causes large yield losses in many Asian countries (Bouman and Toung, 2002; Pantuwan *et al*., 2002), however, some genotypes are more drought resistance than others, out-yielding those exposed to the same degree of water stress. The development of drought resistant cultivars may be assisted if mechanisms of drought resistance are known.

Rice is a notoriously drought-susceptible crop due in part to its small root system, rapid stomatal closure and little circular wax during mild water stress (Hirasawa, 1999). Reduction of photosynthetic activity, accumulation of organic acids and osmolytes, and changes in carbohydrate metabolism, are typical physiological and biochemical responses to drought stress (Tabaeizadeh, 1998).

Water deficit also increases the formation of reactive oxygen species (ROS) resulting in lipid peroxidation, protein denaturation and nucleic acid damage with severe consequences on overall metabolism (Hansen *et al*., 2006).

2.1.4 Effect of drought stress on yield contributing characters and yield

Islam and Gretzmacher (2001) observed in their experiments that plant height and length of panicle were decreased by the water stress at booting stage only. Stress at booting stage affected more than that of flowering in 1000-grain weight, yield and total dry matter production.

Chandra *et al*., (1988) carried out a yield trial on the effect of different irrigation regimes (continuous shallow submergence with 5±2 cm water, important irrigation at 5 day intervals with 4 cm water except during flowering and moderate stress) found that the mean yields of transplanted and direct sown crops were 5.2 t ha^{-1} and 3.7 t ha^{-1}, respectively and continuous shallow submergence produced the highest average yield of 5.6 t ha^{-1}

Islam (1992) conducted an experiment with four irrigation treatments, maximum grain yield of 5.19 t ha^{-1} was obtained in plots maintained 7 to 5 cm standing water. The lowest yield (3.85 t ha^{-1}) was noted in plot, where water level was maintained from 1 cm to saturation.

Karim *et al.,* (1996) carried out a yield experiment in a clay terrace soil to assess grain yield under different irrigation they concluded that limited irrigation, maintaining a moisture regime between field capacity and saturation, significantly decreased grain yield.

It was reported that upland cultivar IRAT109 has higher values in the important traits of relative performance such as relative yield, relative spikelet fertility, relative biomass, relative grain weight, and relative harvest index than those of lowland cultivar Zhenshan97 under drought stress (Yue *et al.,* 2006).

Effect of drought or water stress has been reviewed in details by Singh *et al*. (2010). Water stress is most severe limitation to the productivity of rice (Widawsky and O'Toole, 1990). Drought is a meteorological term and is commonly defined as the inadequacy of water availability including period without significant rainfall that affects the crop growth (Hanson, *et al.,* 1995) and soil moisture storage capacity and it occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought has been recognized as the primary constraint to rainfed rice production (Datta, *et al*., 1975).

Rice is very sensitive to water stress (Tuong and Bouman, 2016). Water scarcity is a severe environmental limitation to plant productivity. Drought induced loss in crop yield may exceeds loses from all other causes, since both the severity and duration of the stress are critical (Farooq *et al.,* 2008).

Drought may delay the phenological development of the rice plant (Inthapan and Fukai, 1988) and affect physiological processes like transpiration, photosynthesis, respiration and translocation of assimilates to the grain (Turner, 1986). Plant processes that depend on cell volume enhancement are particularly sensitive to water deficit. Leaf expansion and leaf gas exchange rates are two such sensitive processes.

At the plant level, reduced leaf area is probably the obvious mechanism by which plants and crops restrict their water loss in response to drought (Sadras and Milory, 1996). Quantification of physiological and morphological responses of rice to water stress is essential to predict the impact of soil and weather conditions on rice production using process-based crop simulation models. Modeling plant responses to water deficit requires not only an understanding but also quantitative relationships for the effects of water deficits on leaf growth expansion and gas exchange rates (Sadras and Milory, 1996).

The effect of water stress on yield decrease of rice is very pronounced during certain period of growth, called the moisture sensitive periods. The most sensitive periods to water deficits are flowering and head development. In an experiment conducted in the Philippines (IRRI, 1973). It has been shown that moisture stress early in the growth of the rice reduced tillering, thereby reduced yield. When moisture stress was extended into reproductive phase, yield loss was significant.

Jana and Ghildyal (1971) examined the effect of varying soil water regime during different growth phases on rice yield. They reported that the soil water stress applied at any of the growth phases reduced rice grain yield, compared to the continuous flooding irrigation. The ripening phase appeared to be most sensitive to compared to the other phases. Soil water stress during the earlier growth phases (vegetative) appeared the production of effective tillers resulting in the reduction of grain yield.

2.2 Effect of salicylic acid on rice plants

2.2.1 Plant height

Kim *et al.* (2018) reported that the NaCl-induced reactive oxygen species (ROS) production led to increased levels of lipid peroxidation in rice plants, which were significantly reduced following SA application. The similar finding was observed for super oxide dismutase; however, catalase (CAT) and ascor-bateperoxidase (APX) were significantly reduced in rice plants treated with SA and NaCl alone and in combination. The relative mRNA expression of OsCATA and OsAPX1 was lower in rice plants during SA stress. Regarding nitrogenous species, S-nitrosothiol (SNO) was significantly reduced initially (one day after treatment [DAT]) but then increased in plants subjected to single or combined stress conditions. Genes related to SNO biosynthesis, S-nitrosoglutathione reductase (GSNOR1), NO synthase-like activity (NOA), and nitrite reductase (NIR) were also assessed. Then RNA expression of GSNOR1 was increased relative to that of the control, whereas OsNOA was expressed at higher levels in plants treated with SA and NaCl alone relative to the control. Then RNA expression of OsNR was decreased in plants subjected to single or combination treatment, except 2 DAT, compared to the control. In conclusion, the current findings suggest that SA can regulate the generation of NaCl-induced oxygen and nitrogen reactive species in rice plants.

Rice is the most important staple food for over two billion people in Asia and for hundreds of millions in Africa and Latin America. To feed the ever increasing population of these regions the world's annual rice production must be increased from the present 560 to 750 million tons by 2020. However, biocontrol of sheath blight disease management has so far proved to be inefficient in bringing down the disease incidence below economic threshold level (ETL). Hence, the application of systemic resistance inducing chemicals along with biocontrol agents would be the suitable alternative strategy to improve the sheath blight disease management in rice. In this present study, the effect of salicylic acid and Pseudomonas fluorescence on growth of Paddy IR-50 was investigated by Usharani *et al* (2014). Among the various treatments tested, maximum growth was observed in the treatment T (Pseudomonas fluoresces seed application + salicylic acid applied on 30 day) and the least parameters were recorded in the control treatment.

2.2.2 Effect of number of tillers hill^{-1}

Issak *et al*., (2017) conducted to study the effect of salicylic acid (SA) as foliar spray on yield and yield contributing characters of BRRI Hybrid dhan3. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and six treatment combinations as, T_1: 0 µM SA, T_2: 200 µM SA, T3: 400 µM SA, T_4: 600 µM SA, T_5: 800 µM SA and T_6: 1000 µM SA. Treatments T_4, T_5 and T_6 showed significant variation on the effective tillers hill^{-1}. The maximum effective tillers hill^{-1} was found in the treatment T_6 (1000 µM SA).

2.2.3 Effect of dry matter production of rice

Yoonha Kim *et al.* (2018) investigated NaCl-induced reactive oxygen species production led to increased levels of lipid peroxidation in rice plants, which were significantly reduced following SA application. A similar finding was observed for super oxide dismutase; however, catalase (CAT) and ascor-beta-peroxidase (APX) were significantly reduced in rice plants treated with SA and NaCl alone and in combination. The relative mRNA expression of OsCATA and OsAPX1 was lower in rice plants during SA stress. Regarding nitrogenous species, S-nitrosothiol (SNO) was significantly reduced initially (one day after treatment [DAT]) but then increased in plants subjected to single or combined stress conditions. Genes related to SNO biosynthesis, S-nitrosoglutathione reductase (GSNOR1), NO synthase like activity (NOA), and nitrite reductase (NIR) were also assessed. Then RNA expression of GSNOR1 was increased relative to that of the control, whereas OsNOA was expressed at higher levels in plants treated with SA and NaCl alone relative to the control. Then RNA expression of OsNR was decreased in plants subjected to single or combination treatment, excepted 2 DAT, compared to the control. In conclusion, the current findings suggest that SA can regulate the generation of NaCl-induced oxygen and nitrogen reactive species in rice plants.

Issak *et al*. (2017) revealed that dry matter production was significantly increased due to the foliar application of SA. At the maximum tillering (MT) stage, the highest dry matter production was observed in T_3 treatment (400 μMm^{-2} SA).

2.2.4 Chlorophyll content of rice

NaCl-induced reactive oxygen species production led to increased levels of lipid per-oxidation in rice plants, which were significantly reduced following SA application.

The impact of exogenous application of different concentrations of salicylic acid (10, 50 and 100 µM) through the rooting medium on the plant growth, the pigment content and the photochemical activities of both photosystem I and photosystem II was investigated. Data revealed that the observed alterations strongly depend on the concentration of applied salicylic acid, as 10 µM is the optimal concentration for the growth and the functional activity of photosynthetic apparatus of rice plants under non-stress conditions. In addition, the concentrations of salicylic acid lower than 100 µM had no effect on the energy transfer between the chlorophyll-protein complexes in thylakoid membranes (Yotsova *et al*. 2018).

2.2.5 Effect of yield of rice

The application of systemic resistance inducing chemicals along with bio control agents would be the suitable alternative strategy to improve the sheath blight disease management in rice. In this present study, the effect of salicylic acid and yield of paddy IR-50 was investigated by Usharani *et al.* (2014). Among the various treatments tested, yield was observed in the treatment T (Pseudomonas fluorescence seed application + Salicylic acid applied on 30 day) and the least parameters were recorded in the control treatment.

Issak *et al*. (2017) stated that the maximum grain yield (9.2 t ha^{-1}) and straw yield (9.22 t ha^{-1}) was found in the treatment T_6 which was identical to T_5. On the other hand, in all cases the lowest results were found in the control treatment. The result showed that grain yield of rice increased with increasing level of SA to up to 1000 µM (T_6 treatment). Our results suggest that foliar spray of SA might be applied to increase the yield of hybrid rice in Bangladesh.

Jini and Joseph (2017) was revealed that the increased accumulation of Na^+ and Cl^- ions by the salt stress was reduced by SA application. An increased concentration of endogenous SA level was detected from the SA-treated rice varieties (ASD16 and BR26) by liquid chromatography electro spray ionization-tandem mass spectrometry. The activities of antioxidant enzymes such as superoxide dismutase, catalase and peroxidase were increased by salt stress whereas decreased by the SA application. The study proved that the application of SA could alleviate the adverse effects of salt stress by the regulation of physiological mechanism in rice plants. In spite of salt stress, it can be applied to the coastal and estuarine regions to increase the rice production.

Vikram Jeet Singh *et al*. (2015) a research was performed to assess the effect of SA along with standard fungicide on sheath infecting pathogen and yield attributes in hybrid rice. Two different concentration of SA (20 and 40 ppm) and Mancozeb (3 and 4 g ml^{-1}) were used at three different stages (booting stage, heading stage and at the time 50 % flowering). Results revealed that significant increase for most of the yield attributes studied for all the treatments over control but found non-significant for panicle $hill^{-1}$. The Area under Diseased Progress Curved (AUDPC) was decreased significantly for all the treatments over control. The correlation between AUDPC and yield parameters was varied. AUDPC was strongly correlated with all the yield attributes. The value of AUDPC was negatively correlated to different yield attributes proving that the pathogen had a damaging effect on the yield attributes of hybrid rice. With the above results it may be concluded that SA has got a significant role in plant defense as well as in enhancing the yield of hybrid rice.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at the central research field of Sher-e-Bangla Agricultural University, Dhaka, Banglsdesh during the period from November 2017 to May, 2018. This chapter deals with a brief description on experimental site, climate, soil, land preparation, methods, experimental design, intercultural operations, data recording and their analysis.

3.1 Site description

The present study was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka, under the Agro-ecological zone of Modhupur Tract, AEZ-28. The location of the site is $23^{0}74^{/}$N latitude and $90^{0}35^{/}$E longitude with an elevation of 8.2 meter from sea level (Appendix I).

3.2 Climate and weather

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, *Aus, Aman, Boro*. Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Meterological Station of Sher-e Bangla Nagar, Dhaka, Bangladesh.

3.3 Soil

The soil belongs to “The Modhupur Tract”, AEZ – 28. Top soil was salty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood level. The selected plot was medium high land.

3.4 Plant materials and features

BRRI dhan28 was used as plant materials for the present study. The variety is recommended for *boro* season, although the variety was popular for cultivating in Aus season BRRI dhan28 was collected from Bangladesh Rice Research Institute (BRRI), Gazipur.

3.5 Experimental details

3.5.1 Treatments

Factor A: different concentrations of salicylic acid (SA)

i. T_0 = 0.0 SA
ii. T_1 = 250 μMm^{-2} SA
iii. T_2 = 500 μMm^{-2} SA
iv. T_3 = 750 μMm^{-2} SA
v. T_4 = 1000 μMm^{-2} SA

Factor B: Different level of drought stress

i. S_0 = Control (normal irrigation)
ii. S_1 = Moderate drought stress (water withheld from flowering stage to season end)
iii. S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

3.5.2 Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. There were 15 treatment combinations. The total numbers of unit pots were 45.

3.6 Growing of crops

3.6.1 Raising seedlings

3.6.1.1 Seed collection

The seeds of the test crop i.e. BRRI dhan28 was collected from Bangladesh Rice Research Institute (BRRI), Joydebpur, Gazipur**.**

3.6.1.2 Seed sprouting

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then it was kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown in nursery bed after 72 hours.

3.6.1.3 Preparation of nursery bed and seed sowing

As per BRRI recommendation seedbed was prepared with 1 m wide adding nutrients as per the requirements of soil. Seeds were sown in the seed bed on December 12, 2017 in order to transplant the seedlings in the pots.

3.6.2 Preparation of the experimental pot

A total of 45 pots were prepared and their individual weight was recorded. Each pot was containing 24 kg of soil. The pots were placed at net house in the department of Agricultural Botany at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

3.6.3 Fertilizers and manure application

The pot soil will be fertilized with cowdung 120 g pot^{-1}, urea 5.16 g pot^{-1}, triple super phosphate (TSP) 4.32 g pot^{-1}, murate of potash (MOP) 24 g pot^{-1} corresponding to 8 ton cowdung ha^{-1}, 215 kg urea ha^{-1}, 180 kg TSP ha^{-1} and 100 kg MP ha^{-1} as a source of NPK. The whole amount of cowdung, TSP, MOP and 1/3rd if urea was applied prior to final preparation of pots.

3.6.4 Uprooting seedlings

The nursery bed was made wet by application of water one day before uprooting the seedlings. The seedlings were uprooted on January 11, 2018 without causing much mechanical injury to the roots.

3.6.5 Transplanting of seedlings in the pot

The seedlings were transplanted in the main pot on January 12, 2018 and the rice seedlings were transplanted in for all treat varieties in the well prepared pots.

3.6.6 Application of Salicylic acid (SA)

In the experiment each of the SA solution were applied in three installments. 1st spray was done at 20 Days after transplanting (DAT). 2nd spray was done after 30 DAT and 3rd spray was done after 40 DAT with a hand sprayer.

3.6.7 Cultural operations

The details of different cultural operations performed during the course of experimentation are given below:

3.6.7.1 Irrigation and drainage

Flood irrigation was applied according to treatments.

3.6.7.2 Gap filling

Gap filling was done for all of the pots at 7-10 days after transplanting (DAT) by planting same aged seedlings.

3.6.7.3 Weeding

Weeding was done from each pot at 40 and 65 DAT. Hand weeding was done from each pot.

3.6.7.4 Plant protection

Furadan 57 EC was applied at the time of final pot preparation and later on other insecticides were applied as and when necessary.

3.8 Harvesting, threshing and cleaning

The rice plant was harvested depending upon the maturity of grains and harvesting was done manually from each pot. Maturity of crop was determined when 80-90% of the grains become golden yellow in color. Two hill selected randomly from each treatment was separately harvested and bundled, properly tagged and then brought to the threshing floor. Enough care was taken for harvesting, threshing and also cleaning of rice seed. Fresh weight of grain and straw were recorded treatment wise. Finally the weight was adjusted to a moisture content of 14%. The straw was sun dried and the yields of grain and straw pot^{-1} were recorded and converted to gmpot^{-1}.

3.9 Data recording

Data on the following parameters were recorded during the course of the experiment:

1. Plant height(cm)
2. Number of tillers hill^{-1}

3. Number of leaves $hill^{-1}$
4. Leaf area index (LAI)
5. Relative water content (%)
6. Leaf membrane stability Index
7. Flag leaf chlorophyll content (μMm^{-2})
8. Root Dry weight $hill^{-1}$
9. Shoot Dry weight $hill^{-1}$
10. Total dry weight $hill^{-1}$
11. Number of panicle $hill^{-1}$
12. Number of filled grain $panicle^{-1}$
13. Number of unfilled grain $panicle^{-1}$
14. Weight of 1000 grains (g)
15. Grain yield (g/pot)
16. Straw yield (g/pot)
17. Harvest index (%)

3.10 Procedure of recording data

3. 10.1 Plant height

The height of plant was recorded in centimeter (cm) at flowering and maturity. Data were recorded as the average of 3 plants at random from each treatment in each replication. The height was measured from the ground level to the tip of the longest panicle.

3. 10.2 Number of tillers $hill^{-1}$

The number of tillers $hill^{-1}$ was recorded at flowering and maturity stage by counting total tillers as the average of same 3 hills selected from each treatment.

3. 10.3 Number of leaves $hill^{-1}$

The number of leaves $hill^{-1}$ was recorded at flowering and maturity stage by counting number of leaves as the average of same 3 hills selected from each treatment.

3.10.4 Leaf area

Leaf area index was estimated manually measuring the length and width of leaf and multiplying by a factor 0.75 as suggested by Yoshida (1981).

3.10.5 Relative water content (%)

Relative water content of leaf was determined at flowering and maturity stage by the method developed by Barrs and Weatherly (1962). Second leaf of randomly select 2 tillers was used for determining relative water content. Fresh weight (FW) immediately recorded, and then leaves was soaked for 4 hours in distilled water at room temperature under a constant light and saturated humidity. Turgid weight (TW) was recorded follow by drying for 24 hours at 80ºC for dry weight (DW). Relative water content (RWC) was calculated according to the following formula:

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

3.10.6 Leaf membrane stability index

The leaf strips (0.2g) of uniform size was taken in two sets of test tubes containing 10 ml of distilled water. Test tubes in one set was kept at 40ºC in a water bath for 30 min and electrical conductivity of the water containing the samples was measured (C_1). Test tubes in the second set was incubate at 100ºC in the boiling water bath for 15 min and electrical conductivity (C_2) was measured. MSI was calculated by following formula:

$MSI = [1-(C_1/C_2)] \times 100$

C_1 = Electrical conductivity of water containing the sample in test tube of set 1.

C_2 = Electrical conductivity of water containing the sample in test tube of set 2.

3.10.7 Flag leaf chlorophyll content (μMm^{-2})

Five leave from each experimental unit was selected randomly and detached from the plant and frozen. Two gram frozen leaves from each sample was put into a mortar and finely ground with pestle in 80% acetone and keep in dark for few hours to allow the leaf tissues to be thoroughly homogenized. Samples then centrifuge for 10 min @ 6000 rpm. Absorbance of supernatant was determined at 647 nm for chlorophyll ‘a’ and at 664 nm for chlorophyll ‘b’ by UV spectrophotometer. Absorbance values were used in following expression to quantify chlorophyll as reported by

Chlorophyll “a” (μMm^{-2}) = 13.19 A664-2.57 A647

Chlorophyll “b” (μMm^{-2}) = 22.10 A647-5.26 A664

Total Chlorophyll Content (μMm^{-2}) = 7.93 A664+19.53 A647

3.10.8 Root dry weight

Roots were carefully cleaned with running tap water and finally washed with distilled water. Then the root samples were oven-dried to a constant weight at 70^0 C. The mean root dry weight hill^{-1} was calculated for each treatment.

3.10.9 Shoot dry weight

After separation of roots, the samples of stem, leaf and panicle were oven-dried to a constant weight at 70^0 C. Then the shoot dry weight was calculated from the summation of leaf and stem.

3.10.10 Total dry weight hill^{-1}

Total dry matter hill^{-1} was recorded at the time of harvest by drying the plant samples. Data were recorded as the average of 3 sample hill pot^{-1} selected at random and expressed in gram.

3.10.11 Number of panicle hill $^{-1}$

Average number of panicle hill $^{-1}$ was calculated by counting the number of panicle hill $^{-1}$.

3.10.12 Number of filled grain panicle^{-1}

Average number of filled grains panicle^{-1} was calculated by counting the number of filled grain of 5 panicles hill^{-1}.

3.10.13 Number of unfilled grain panicle^{-1}

Number of unfilled grains panicle^{-1} was also counted.

3.10.14 Weight of 1000 grains

One thousand grains were counted randomly from the total cleaned harvested grains of each individual pot and then weighed in grams and recorded.

3.10.15 Grain yield

Grain yield was determined from hill of the pot and expressed as kg $hill^{-1}$ on 14% moisture basis. Grain moisture content was measured by using a digital moisture tester.

3.10.16 Straw yield

Straw yield was determined from hill each of the pot. After threshing, the sub-sample was oven dried to a constant weight and finally converted to kg $hill^{-1}$.

3.10.17 Harvest index (HI)

It denotes the ratio of economic yield (grain yield) to biological yield and was calculated with following formula.

HI (%) = Grain yield / Biological yield ×100

3.11 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques using MSTAT-C package and the mean values were separated using least significant differences (LSD) test at 5% level of significance.

CHAPTER IV

RESULTS AND DISCUSSION

The experimental results regarding the effect of foliar application of salicylic acid on mitigation of drought stress in *boro* rice have been presented and discussed in this chapter. The effects of salicylic acid and different level of drought stress and their interaction on growth, yield and yield contributing characters have been presented below.

4.1. Plant height

4.1.1 Effect of salicylic acid

Significant influenced was remarked in terms of plant height under the present study as influenced by SA at different growth stages (Figure 1). Results showed that exogenous application of SA @ 750 µMm^{-2} (T_3) showed the highest plant height (80.15 and 90.85cm at flowering and maturity stages, respectively), which was statistically identical with other treatment. The competition on plant height among the

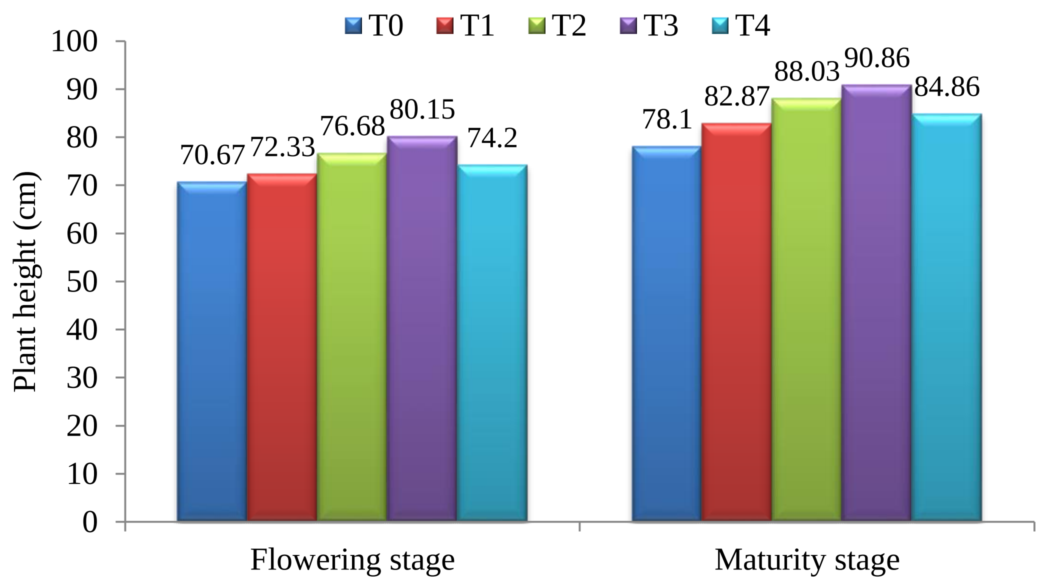

Figure 1. Effect of salicylic acid on plant height of rice

T_0 = 0.0 µMm^{-2} SA, T_1 = 250µMm^{-2} SA, T_2 = 500µMm^{-2} SA, T_3 = 750µMm^{-2} SA, T_4 = 1000µMm^{-2} SA different doses of SA, without exogenous application of SA (T_0) showed the shorter plant (70.67 and 78.10 cm at flowering and maturity stages, respectively). Plant height increased with increasing SA at certain level. Hussein *et al*. (2007) reported that the application of SA to the cereal crop enhanced productivity due to an improvement in all growth characteristics including plant height.

4.1.2 Effect of different level of drought stress

Plant height as influenced by different level of drought stress on *boro rice* (Figure 2). Results showed that the tallest plant (80.26 cm and 92.02 cm at flowering and maturity stages, respectively) was recorded by S_0 (normal irrigation) which was followed by S_2 (Sever drought stress water withheld from panicle initiation stage to season end). The results obtained from S_1 (moderate drought stress (water withheld from flowering stage to season end) showed the shortest plant (68.33 and 78.14 cm at flowering and maturity stages, respectively). The results supported the findings of Sokoto and Muhammad, (2014) who observed various plant heights due to water stress among different varieties.

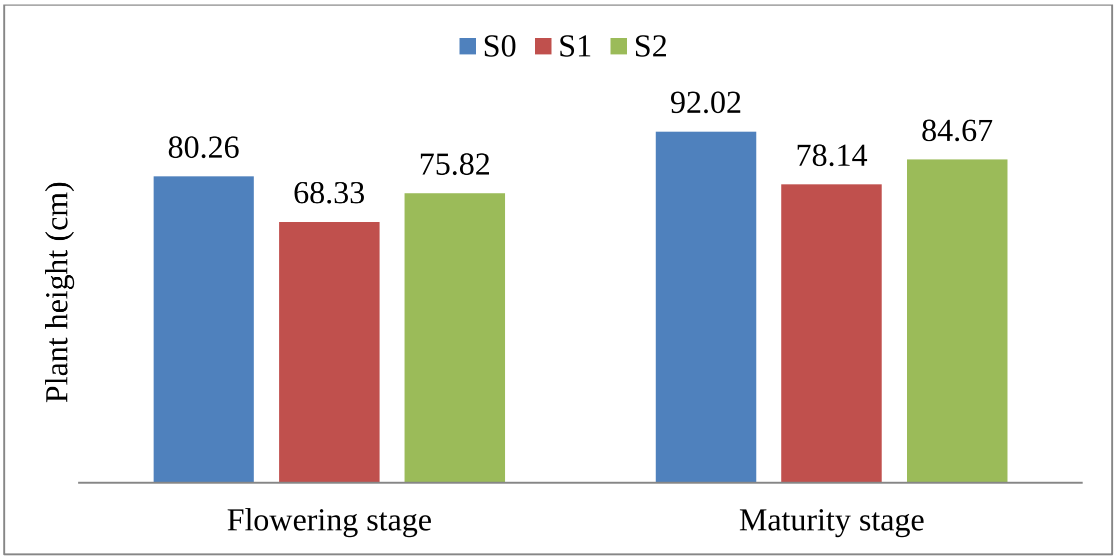

Figure 2. Effect of different level of drought stress on plant height of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.1.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress significantly influenced the plant height at different growth stages of *boro* rice (Table 1). Results indicated that the longest plant (85.72 and 97.67 cm at flowering and at maturity stages, respectively) was with T_3S_0 (exogenous application of SA @ 750 µMm^{-2} with normal irrigation). On the other hand, T_0S_1 (without exogenous application of SA with moderate drought stress (water withheld from flowering stage to season end) showed the lowest plant height (65.00 and 70.00 cm at flowering and at maturity stages, respectively). The results obtained from all other treatments at different growth stages on plant height gave significantly different results

Table 1. Interaction effect of salicylic acid and different level of drought stress on plant height of rice

Treatment combinations	Plant height (cm)	
	Flowering stage	Maturity stage
T_0S_0	75.00 cd	85.60 def
T_0S_1	65.00 g	70.50 j
T_0S_2	72.00 de	78.20 hi
T_1S_0	78.00 bc	90.00 bcd
T_1S_1	66.00 fg	76.20 i
T_1S_2	73.00 de	82.40 fgh
T_2S_0	82.03 ab	94.30 ab
T_2S_1	70.00 ef	81.80 fgh
T_2S_2	78.00 bc	88.00 cde
T_3S_0	85.72 a	97.67 a
T_3S_1	73.84 de	83.80 ef
T_3S_2	80.89 b	91.07 bc
T_4S_0	80.56 b	92.51bc
T_4S_1	66.81 fg	78.41 ghi
T_4S_2	75.21 cd	83.68 efg
$LSD_{(0.05)}$	3.66	3.93
CV (%)	3.38	3.19

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.2 Number of tillers hill^{-1}

4.2.1 Effect of salicylic acid

Number of tillers hill^{-1} was significantly influenced by SA used in the present study (Figure 3). Results showed that T_3 showed the highest number of tillers hill^{-1} (13.31 and 29.72 at flowering and at maturity stages, respectively). Comparing tiller producing capacity among the four treatments, control treatment (T_0) showed the lowest number of tillers hill^{-1} (8.33 and 19.67 at flowering and maturity stages, respectively).

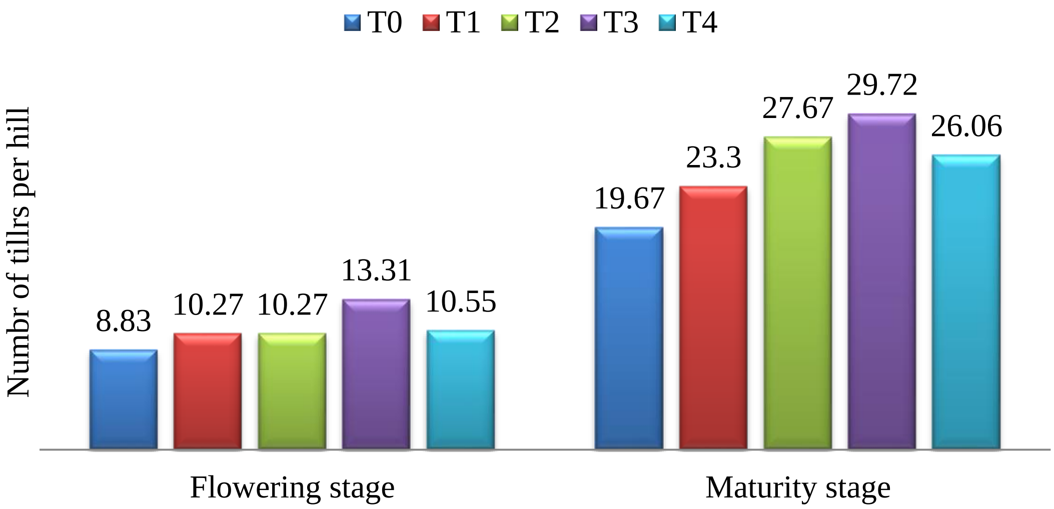

Figure 3. Effect of salicylic acid on number of tillers hill^{-1} of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.2.2 Effect of different level of drought stress

The number of tillers hill^{-1} as influenced by different level of drought stress on *boro* rice at different growth stages (Figure 4). Results showed that at all growth stage the highest number of tillers hill^{-1} was recorded by S_0 (13.97 and 29.8 at flowering and maturity stages, respectively) which was closely followed by S_2. The results obtained from S_1 showed the lowest number of tillers hill^{-1} (8.69 and 21.41at flowering and maturity stages, respectively). Similar trend of tillering habits with different varieties of rice due to water stress has been reported by Murty (1987), Castilo *et al*. (1987) IRRI (1973) and Islam *et al*. (1994).

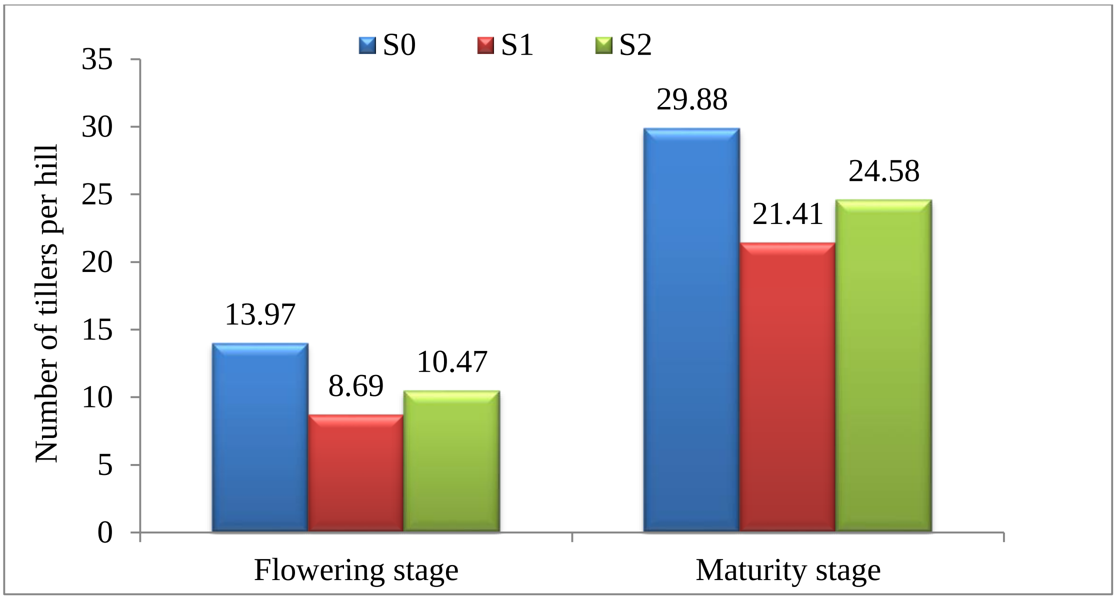

Figure 4. Effect of different level of drought stress on number of tillers hill^{-1} of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.2.3 Interaction effect of salicylic acid and different level of drought stress on number of tillers hill^{-1}

Interaction effect of SA and different level of drought stress significantly influenced the number of tillers hill^{-1} at different growth stages of *boro* rice (Table 2). Results indicated that the highest number of tillers hill^{-1} (17.14 and 36.11 at flowering and maturity, respectively) was with T_3S_0 which was closely followed by T_2S_0.The results recorded from T_0S_1 showed the lowest number of tillers hill^{-1} 7.00 and 17.00 at flowering and maturity stages, respectively) which was statistically identical with other treatment. The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of number of tillers hill^{-1}.

Table 2. Interaction effect of salicylic acid and different level of drought stress number of tillers hill^{-1} of rice

Treatment combinations	Number of tillers hill^{-1}	
	Flowering stage	**Maturity stage**
T_0S_0	11.00 bd	22.00 hi
T_0S_1	7.00 g	17.00 j
T_0S_2	8.50 fg	20.00 i
T_1S_0	13.00 c	27.00 de
T_1S_1	8.00 fg	20.00 i
T_1S_2	9.80 ef	23.00 gh
T_2S_0	15.30 b	33.00 b
T_2S_1	9.80 ef	24.00 fgh
T_2S_2	11.50 cde	26.00 ef
T_3S_0	17.14 a	36.11 a
T_3S_1	10.37 e	24.46 fgh
T_3S_2	12.42 cd	28.58 cd
T_4S_0	13.42 bc	31.27 bc
T_4S_1	8.27 fg	21.57 hi
T_4S_2	9.97 ef	25.32 efg
$LSD_{(0.05)}$	1.57	2.32
CV (%)	9.84	6.33

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.3 Number of leaves hill^{-1}

4.3.1 Effect of salicylic acid

Significant variation was observed by salicylic acid used in the present study in respect of number of leaves hill^{-1} (Figure 5). Results indicated that T_3 showed the highest number of leaves hill^{-1} (95.01 and 63.16 at flowering and maturity stages, respectively) followed by T_2 treatment. Among the treatment, control (T_0) showed the lowest number of leaves hill^{-1} (75.00 and 49.67 at flowering and maturity stages, respectively). The number of leaf increased with increasing doses of SA at certain level. The leaf number increased with the advancement of growth stages.

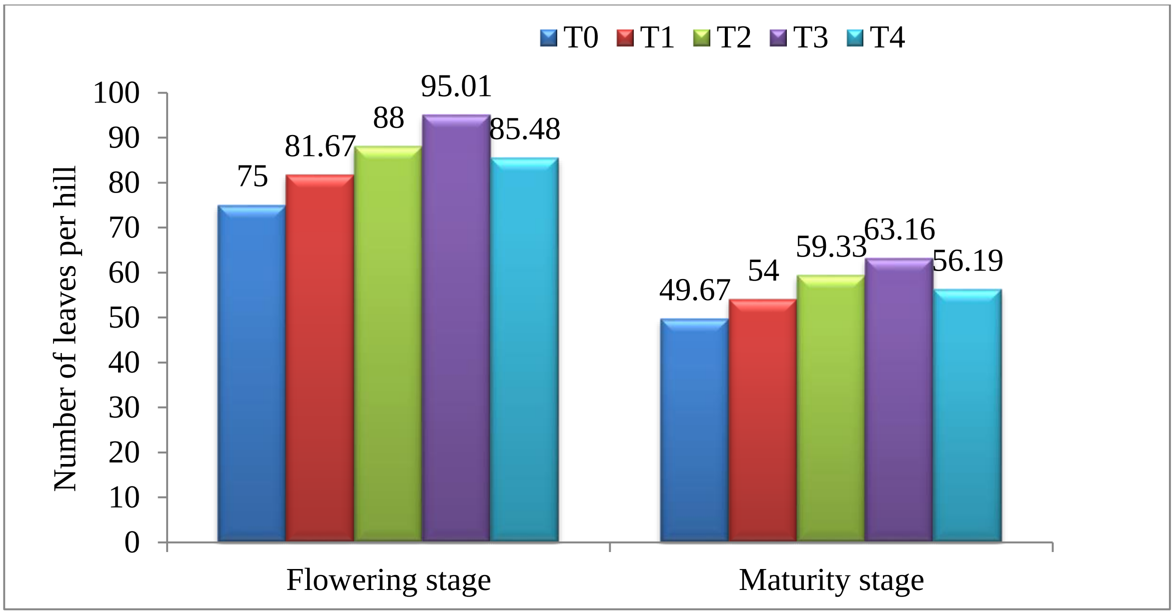

Figure 5. Effect of salicylic acid on number of leaves hill^{-1} of rice

T_0 = 0.0 µMm^{-2} SA, T_1 = 250 µM SA, T_2 = 500 µMm^{-2} SA, T_3 = 750 µMm^{-2} SA, T_4 = 1000 µMm^{-2} SA

4.3.2 Effect of different level of drought stress

Significantly different variation was observed in case of number of leaves hill^{-1} as influenced by different level of drought stress on *boro* rice at different growth stages (Figure 6). Results showed that at all growth stage the highest number of leaves hill^{-1}was recorded by S_0 (93.88 and 62.40 at flowering and maturity stages, respectively) which was closely followed by S_2. The results obtained from S_1 showed the lowest number of leaves hill^{-1} (76.64 and 50.79 at flowering and maturity stages, respectively).The result have supported Hossain (2001) who have suggested that water stress might inhibit photosynthesis and produce less amount of assimilates which resulted in lower number of leaves.

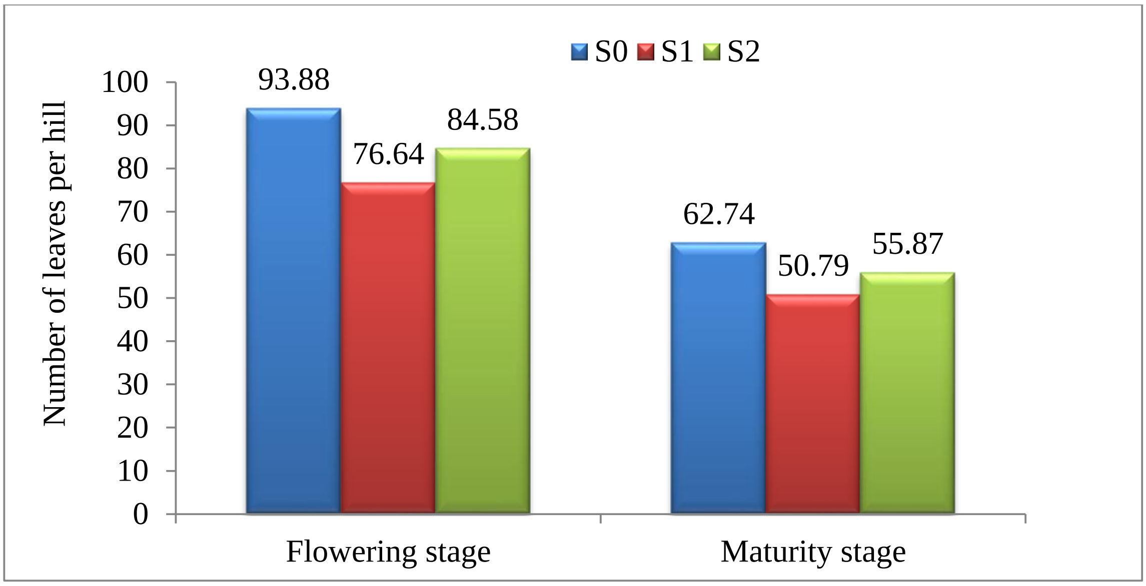

Figure 6. Effect of different level of drought stress on number of leaves hill^{-1} of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.3.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of salicylic acid and different level of drought stress had significant influence on number of leaves hill^{-1} at different growth stages of the *boro* rice (Table 6). Results indicated that the highest number of leaves hill^{-1} (106.12 and 69.80 at flowering and maturity stages, respectively) was with T_3S_0 which was closely followed by T_2S_0 and T_4S_0. The results recorded from T_0S_1 showed the lowest number of leaves hill^{-1} (70.00 and 45.00 at flowering and maturity stages, respectively) which was statistically identical with other treatment. The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of number of leaves hill^{-1}.

Table 3. Interaction effect of salicylic acid and different level of drought stress on number of leaves hill^{-1} of rice

Treatment combinations	Number of leaves hill^{-1}		Leaf area index (LAI)
	Flowering stage	Maturity stage	
T_0S_0	80.00 efg	55.00 efg	4.30 g
T_0S_1	70.00 h	45.00 j	3.70 i
T_0S_2	75.00 gh	49.00 hij	3.95 h
T_1S_0	90.00 cd	60.00 cd	4.55 cdef
T_1S_1	74.00 gh	48.00 ij	3.98 h
T_1S_2	81.00 efg	54.00 fg	4.28 g
T_2S_0	98.00 b	66.00 ab	4.85 b
T_2S_1	79.00 fg	53.00 fgh	4.35 fg
T_2S_2	87.00 de	59.00 cde	4.63 bcde
T_3S_0	106.12 a	69.80 a	5.14 a
T_3S_1	84.29 def	57.03 def	4.47 efg
T_3S_2	94.62 bc	62.63 bc	4.73 bcd
T_4S_0	95.26 bc	62.89 bc	4.79 bc
T_4S_1	75.91gh	50.94 ghi	4.28 g
T_4S_2	85.26 def	54.74 efg	4.51 defg
$LSD_{(0.05)}$	6.30	3.93	0.19
CV (%)	5.12	4.81	3.07

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.4 Leaf area index

4.4.1 Effect of salicylic acid

Leaf area index was significantly influenced by salicylic acid used in the present study (Figure 7). The T_3 treatment showed the highest leaf area index (4.78) which was statistically identical with other treatments. The control treatment (T_0) showed the lowest leaf area index (3.98). These results might be due to cause of proper nutrient supply mechanism from soil to the plants, light intensity and light holding capacity of salicylic acid and above all phenotypic characters of the varieties.

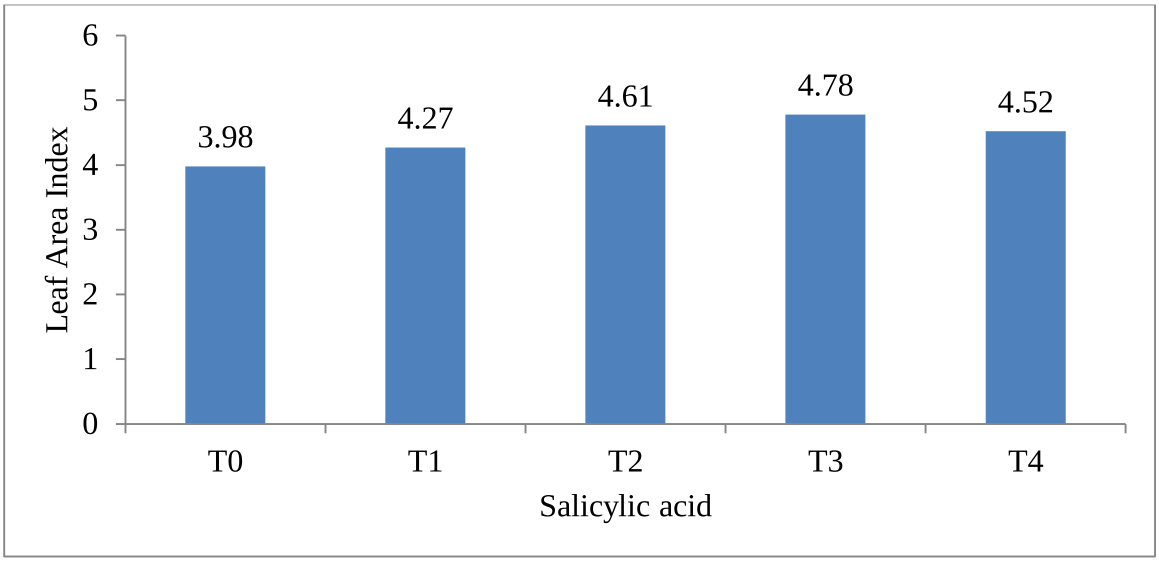

Figure 7. Effect of salicylic acid on leaf area index of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.4.2 Effect of different level of drought stress

Different level of drought stress had significant effect on leaf area index (Figure 8). The highest leaf area index was recorded by S_0 (4.73), which were closely followed by S_2. The results obtained from the lowest leaf area index (4.16) were found in S_1 treatment.

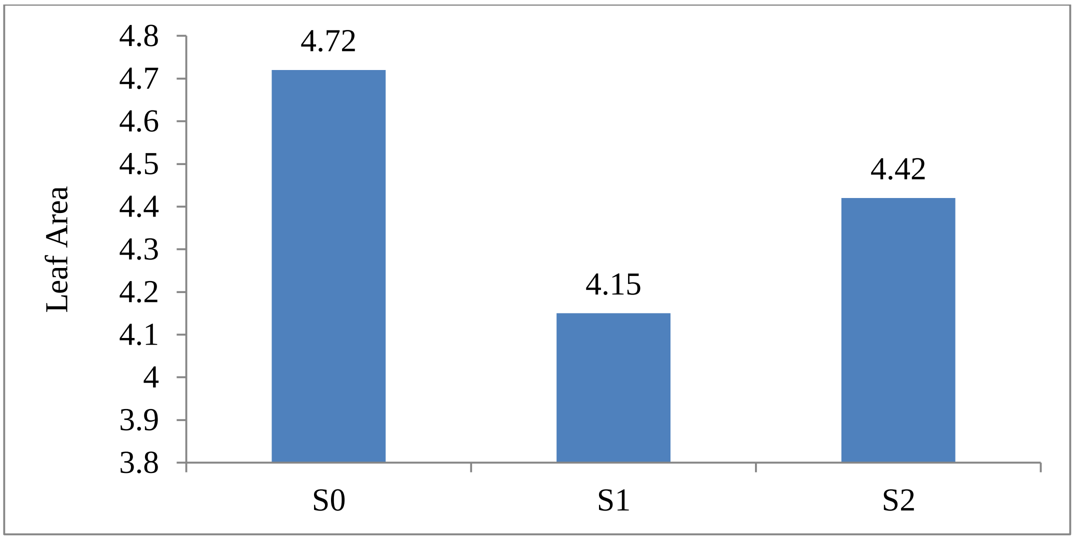

Figure 8. Effect of different level of drought stress on leaf area of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.4.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of salicylic acid and different level of drought stress had significant influence on leaf area index (Table 3). Results indicated that the highest leaf area index (5.13) was with T_3S_0 which was statistically identical with other and closely followed by T_2S_0. The results recorded from T_0S_1 showed the lowest leaf area index (3.70). The results obtained from all other treatments combinations at different growth stages showed significantly different results compared to the highest and the lowest result of leaf area index.

4.5 Relative water content

4.5.1. Effect of salicylic acid

Relative water content (RWC) signifies the relative water content of plant (Figure 9). The relative water content was influenced by the salicylic acid at flowering and at maturity stages. The highest RWC (58.67 and 77.27 % at flowering and maturity stages, respectively) was obtained from T_3, which was statistically identical with other treatments, and that was lowest (35.34 and 50.33% at flowering and maturity stages, respectively) in T_0 (control) treatment.

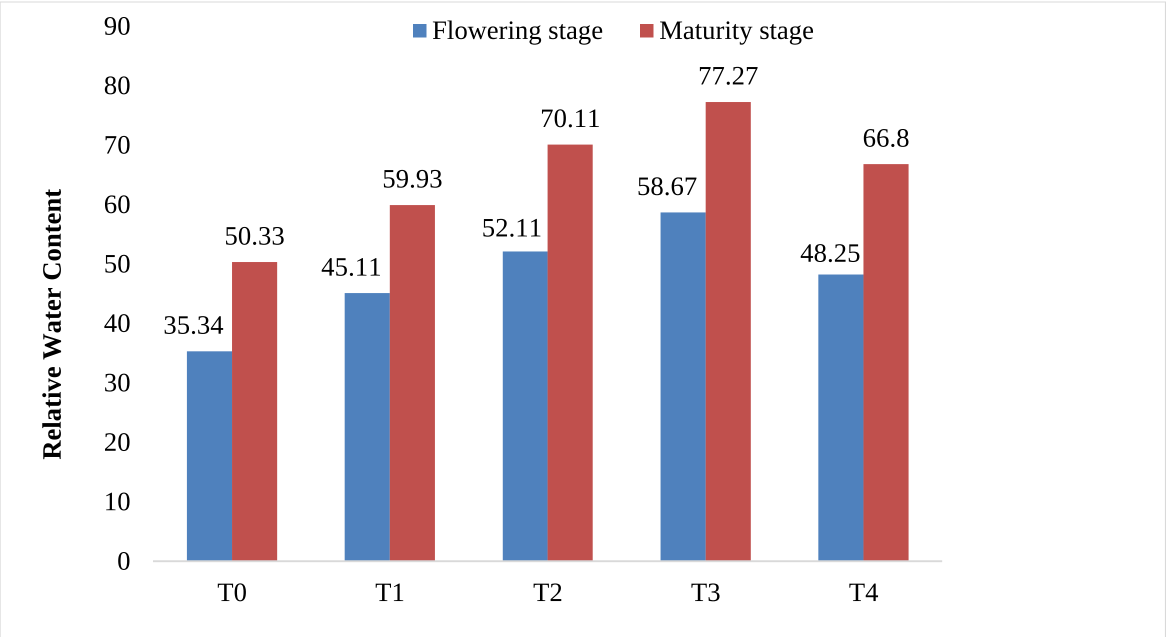

Figure 9. Effect of salicylic acid on relative water content of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.5.2 Effect of different level of drought stress

Relative water content was influenced by different level of drought stress at flowering and maturity (Figure 10). The highest RWC (56.3 and 72.83% at flowering and maturity stages, respectively) was obtained from S_0 treatment and the lowest RWC (39.49 and 57.19% at flowering and maturity stages, respectively) was obtained in S_1 treatment.

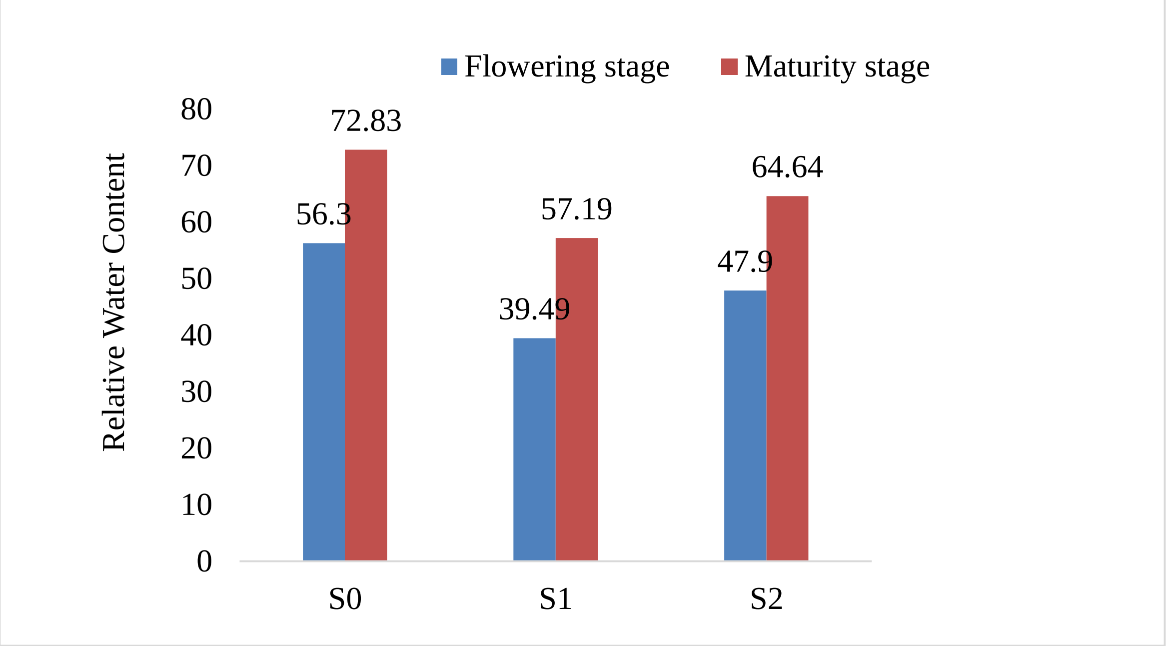

Fig.10. Effect of different level of drought stress on the relative water content of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.5.3. Interaction effect of salicylic acid and different level of drought stress

Interaction of salicylic acid and different level of drought stress had a significant influence on relative water content of rice. The highest RWC (67.36 and 87.51% at flowering and maturity stages, respectively) was obtained from T_3S_0 treatment, which was statistically identical with other treatments while the lowest (30.00 and 45.33 % at flowering and maturity stages, respectively) with T_0S_1 (Table 4).

Table 4. Interaction effect of salicylic acid and different level of drought stress on Relative water content

Treatment combinations	Relative Water Content (%)	
	Flowering stage	Maturity stage
T_0S_0	41.00 efg	55.33 fg
T_0S_1	30.00 h	45.33 h
T_0S_3	35.02 gh	50.33 gh
T_1S_0	50.33 cd	68.33 cde
T_1S_1	40.00 efg	53.33 fgh
T_1S_2	45.00 def	58.13 fg
T_2S_0	63.00 ab	80.00 ab
T_2S_1	40.67 efg	60.33 ef
T_2S_2	52.67 cd	70.00 cd
T_3S_0	67.36 a	87.51a
T_3S_1	49.99 d	68.04 de
T_3S_2	58.67 bc	76.25 bc
T_4S_0	59.79 abc	72.99 bcd
T_4S_1	36.78 fgh	58.92 efg
T_4S_2	48.17 de	68.51 cde
$LSD_{(0.05)}$	7.69	7.74
CV(%)	11.08	8.24

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.6 Leaf membrane stability index

4.6.1. Effect of salicylic acid

Membrane stability index is also influence significantly by salicylic acid at flowering and maturity stages (Figure 11). The highest membrane stability index (26.41 and 4.18 at flowering and maturity stages, respectively) was obtained from T_3 treatment and the lowest (19.71 and 2.26% at flowering and maturity stages, respectively) in T_0 treatment.

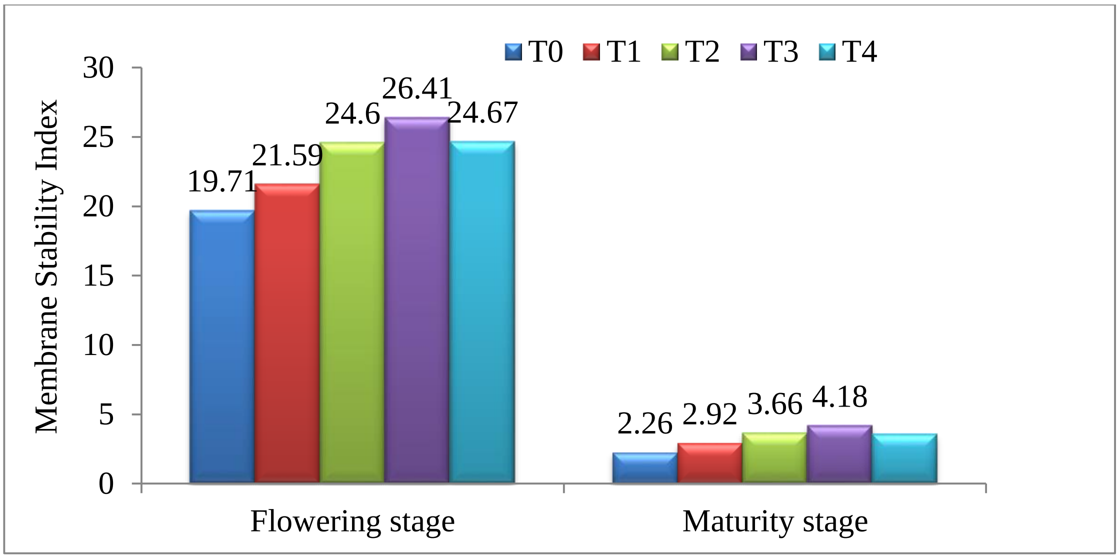

Figure 11. Effect of salicylic acid on the membrane stability index of rice

T_0 = 0.0 µMm^{-2} SA, T_1 = 250 µMm^{-2} SA, T_2 = 500 µMm^{-2} SA, T_3 = 750 µMm^{-2} SA, T_4 = 1000 µMm^{-2} SA

4.6.2. Effect of different level of drought stress

Membrane stability index was significantly influenced by different level of drought stress at flowering and maturity stages (Figure 12). However, the highest membrane stability index (25.69 and 4.43 % at flowering and maturity stages, respectively) was obtained from S_0 and the lowest membrane stability index (21.29 and 2.31 %membrane stability index) from S_1 treatment.

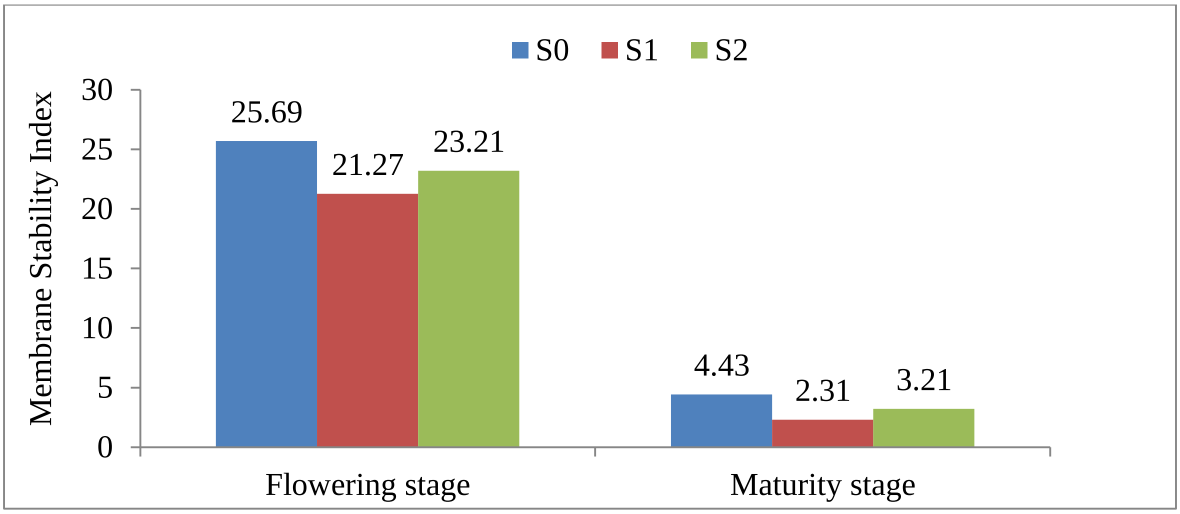

Fig.12. Effect of different level of drought stress on the membrane stability index of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.6.3. Interaction effect of salicylic acid and different level of drought stress

Interaction of salicylic acid and different level of drought stress had a significant influence on membrane stability index at flowering and maturity stages. The highest membrane stability index (29.72 and 5.48 at flowering and maturity stages, respectively) was obtained from T_3S_0 treatment, while the shortest (17.90 and 1.33 at flowering and maturity stages, respectively) was found in T_0S_1 treatment (Table 5).

Table 5. Interaction effect of salicylic acid and different level of drougt stress on membrane stability index of rice

Treatment combinations	Membrane stability index	
	Flowering stage	**Maturity stage**
T_0S_0	21.44 h	3.22 ef
T_0S_1	17.90 j	1.33 i
T_0S_2	19.78 i	2.23 gh
T_1S_0	23.07 defg	3.98 cd
T_1S_1	19.77 i	1.88 hi
T_1S_2	21.94 gh	2.90 ef
T_2S_0	26.57 bc	4.84 b
T_2S_1	22.86 efgh	2.65 fg
T_2S_2	24.37 d	3.48 de
T_3S_0	29.72 a	5.48 a
T_3S_1	23.71def	3.01ef
T_3S_2	25.79 c	4.05 cd
T_4S_0	27.66 b	4.64 bc
T_4S_1	22.19 fgh	2.69 fg
T_4S_2	24.16 de	3.37 def
$LSD_{(0.05)}$	1.23	0.56
CV (%)	3.64	11.63

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.7 Leaf chlorophyll-a content of rice

4.7.1 Effect of salicylic acid

Leaf chlorophyll-a content was significantly influenced by salicylic acid. The variation in chlorophyll-a content among the studied treatments was assessed at flowering and maturity stages (Figure 13). The T_3 had the highest (27.35 and 15.58 μM at flowering and maturity stages, respectively) chlorophyll-a content. The lowest chlorophyll-a content was recorded in T_0 (22.23 and 10.11μMm^{-2} at flowering and maturity stages, respectively).

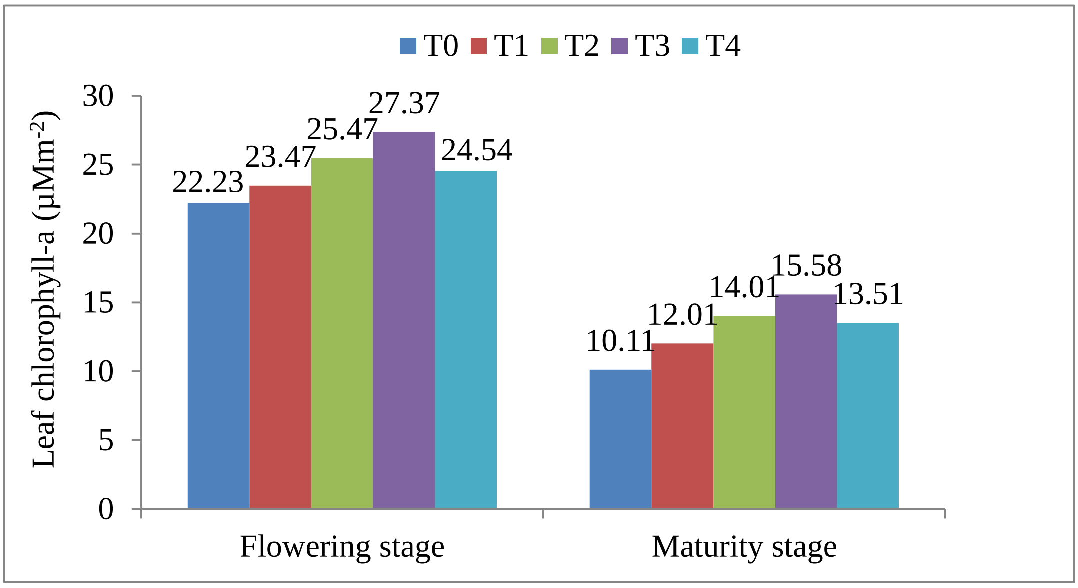

Figure13. Effect of salicylic acid on leaf chlorophyll-a content of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.7.2 Effect of different level of drought stress

The content of chlorophyll-a was varied significantly by different level of drought stress (Figure 14).The S_0 treatment was highest (27.18 and 14.95 μMm^{-2} at flowering and maturity stages, respectively) of all the studied entries. The lowest chlorophyll- a content was recorded in S_1 (22.48 and 11.24 μMm^{-2} at flowering and maturity stages, respectively).

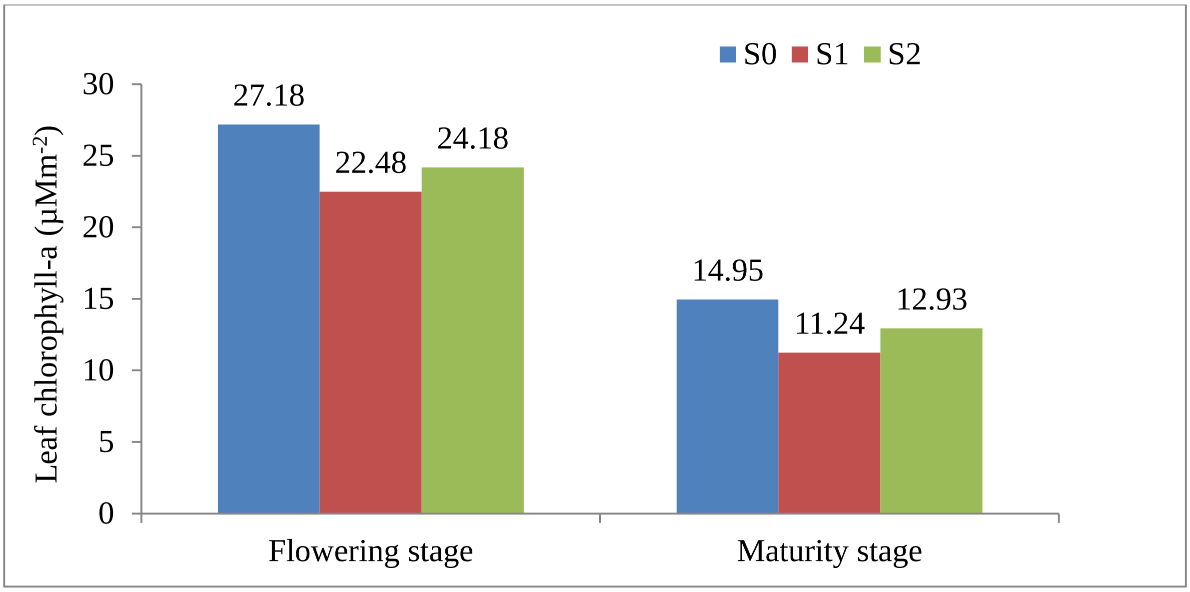

Figure 14. Effect of different level of drought stress on leaf chlorophyll-a content of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.7.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on chlorophyll-a content (Table 6). The highest chlorophyll-a content (30.12 and 17.55 µM m^{-2}at flowering and maturity stages, respectively) was with T_3S_0 which was statistically identical with other and closely followed by T_2S_0. The results recorded from T_0S_1 showed the lowest chlorophyll-a content (20.01 and 8.32 µMm^{-2} at flowering and maturity stages, respectively).

Table 6. Interaction effect of salicylic acid and different level of drought stress on leaf chlorophyll-a content of rice

Treatment combinations	Leaf chlorophyll-a (μMm^{-2})	
	Flowering stage	Maturity stage
T_0S_0	24.56 def	12.00 f
T_0S_1	20.01 i	8.32 h
T_0S_2	22.13 gh	10.00 g
T_1S_0	26.00 cd	14.03 cd
T_1S_1	21.33 hi	10.00 g
T_1S_2	23.07 fgh	12.00 f
T_2S_0	28.07 b	16.02 b
T_2S_1	23.33 efg	12.00 f
T_2S_2	25.00 de	14.00 cd
T_3S_0	30.12 a	17.55 a
T_3S_1	24.50 def	13.62 cde
T_3S_2	27.42 bc	15.56 b
T_4S_0	27.16 bc	15.16 bc
T_4S_1	23.21 efgh	12.26 ef
T_4S_2	23.26 efgh	13.11 def
LSD	1.49	1.29
CV	4.17	6.82

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 levels of probabilities

4.8 Leaf chlorophyll-b content of rice

4.8.1 Effect of salicylic acid

Leaf chlorophyll-b content was significantly influenced by SA. The variation in chlorophyll-b content among the studied treatments was assessed at flowering and maturity stages (Figure 15). The T_3 had the highest (16.83 and 6.28 μMm^{-2} at flowering and maturity stages, respectively) chlorophyll-b content. The lowest chlorophyll-b content was recorded in T_0 (11.52 and 3.46 μMm^{-2} at flowering and maturity stages, respectively).

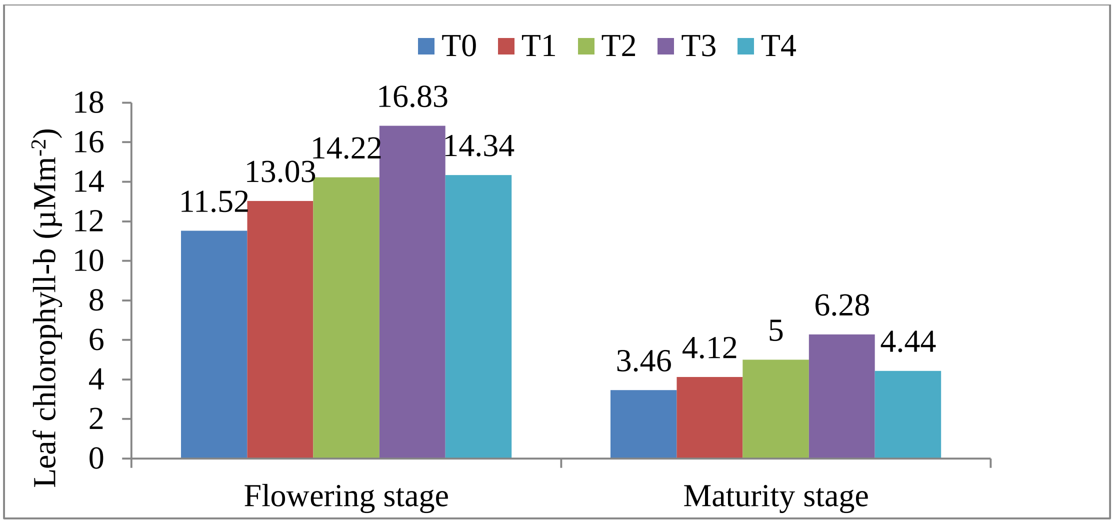

Figure 15. Effect of salicylic acid on leaf chlorophyll-b content of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 25 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.8.2 Effect of different level of drought stress

The content of chlorophyll-b was varied by different level of drought stress (Figure 16). The S_0 treatment was highest (16.11 and 5.53 μMm^{-2} at flowering and maturity stages, respectively) of all the studied entries. The lowest chlorophyll-b content was recorded in S_1 (12.28 and 3.86 μMm^{-2} at flowering and maturity stages, respectively).

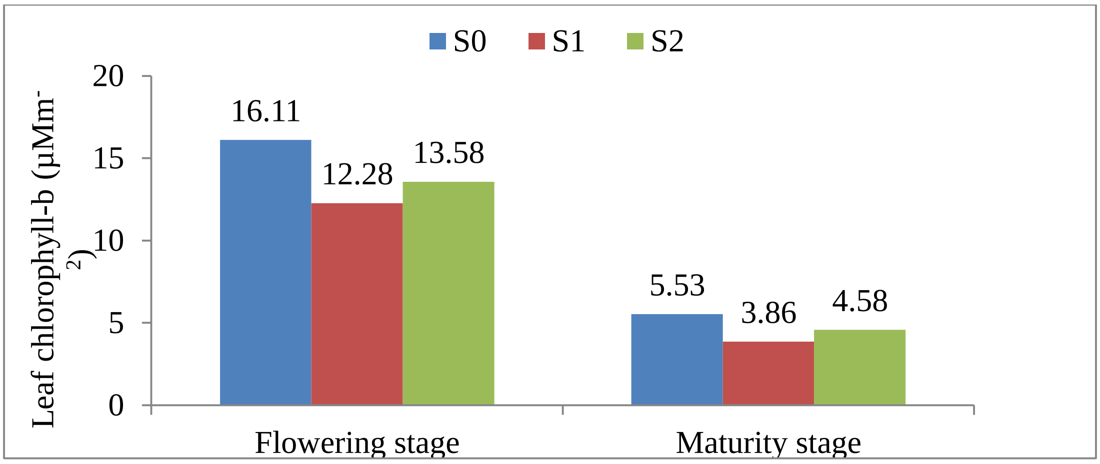

Figure 16. Effect of different level of drought stress on leaf chlorophyll-b content of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from Panicle initiation stage to season end)

4.8.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on chlorophyll-b content (Table 7). The highest chlorophyll-b content (19.32 and 7.60 µMm^{-2} at flowering and maturity stages) was with T_3S_0 which was statistically identical with closely followed by T_2S_0. The results recorded from T_0S_1 showed the chlorophyll-b content (10.02 and 2.83 µMm^{-2} at flowering and maturity stages, respectively).

Table 7. Interaction effect of salicylic acid and different level of drought stress on leaf chlorophyll-b content of rice

Treatment combinations	Leaf chlorophyll-b (µMm^{-2})	
	Flowering stage	**Maturity stage**
T_0S_0	13.02 ef	4.00 cd
T_0S_1	10.0 2h	2.83 d
T_0S_2	11.53 fgh	3.55 d
T_1S_0	15.10 cd	5.02 bc
T_1S_1	11.02 gh	3.33 d
T_1S_2	12.97 ef	4.02 cd
T_2S_0	17.00 b	6.00 b
T_2S_1	13.00 ef	4.00 cd
T_2S_2	12.67efg	5.00 bc
T_3S_0	19.32 a	7.60 a
T_3S_1	14.67 d	5.10 bc
T_3S_2	16.50 bc	6.15 b
T_4S_0	16.10 bcd	5.06 bc
T_4S_1	12.68 efg	4.06 cd
T_4S_2	14.25 de	4.21 cd
$LSD_{(0.05)}$	1.33	1.07
CV (%)	6.57	15.90

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.9 Total leaf chlorophyll content

4.9.1 Effect of salicylic acid

Leaf total chlorophyll content was influenced by salicylic acid. The variation in total chlorophyll content among the studied treatments was assessed at flowering and maturity stages (Figure 17). The T_3 had the highest (44.18 and 21.86 μMm^{-2} at flowering and maturity stages, respectively) total chlorophyll content. The lowest chlorophyll content was recorded in T_0 (33.76 and 13.57 μMm^{-2} at flowering and maturity stages, respectively).

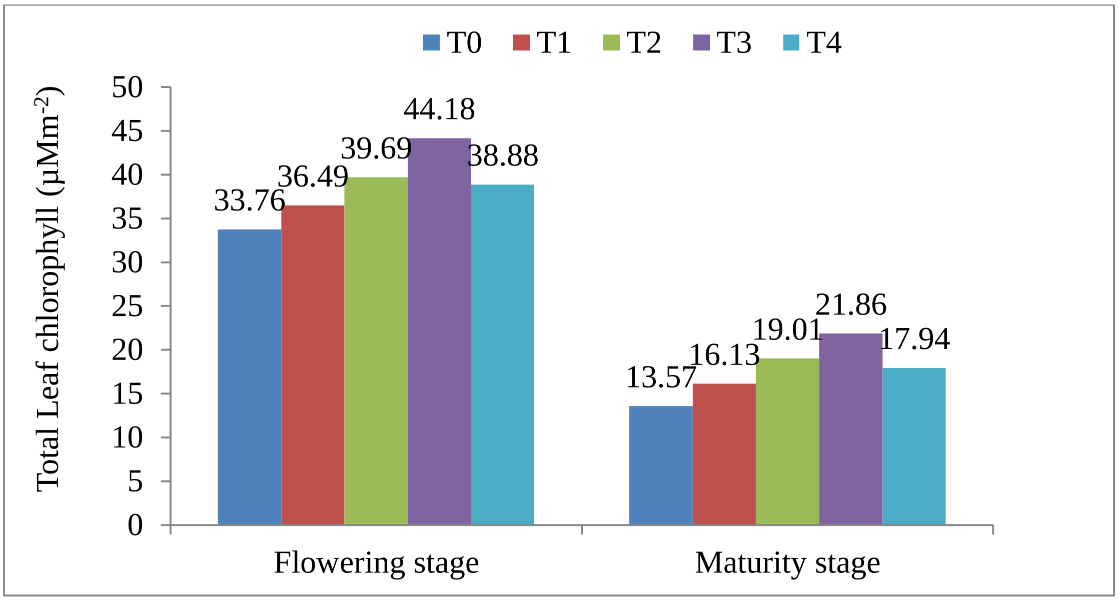

Figure 17. Effect of salicylic acid on total leaf chlorophyll content of rice

T_0 = 0.0 μMm^{-2} SA, T_1 = 250 μMm^{-2} SA, T_2 = 500 μMm^{-2} SA, T_3 = 750 μMm^{-2} SA, T_4 = 1000 μMm^{-2} SA

4.9.2 Effect of different level of drought stress

The content of total chlorophyll was varied by different level of drought stress (Figure 18). The S_0 treatment was highest (43.29 and 20.48 μMm^{-2} at flowering and maturity stages, respectively) of all the studied entries. The lowest total chlorophyll content was recorded in S_1 (34.75 and 15.10 μMm^{-2} at flowering and maturity stages, respectively).

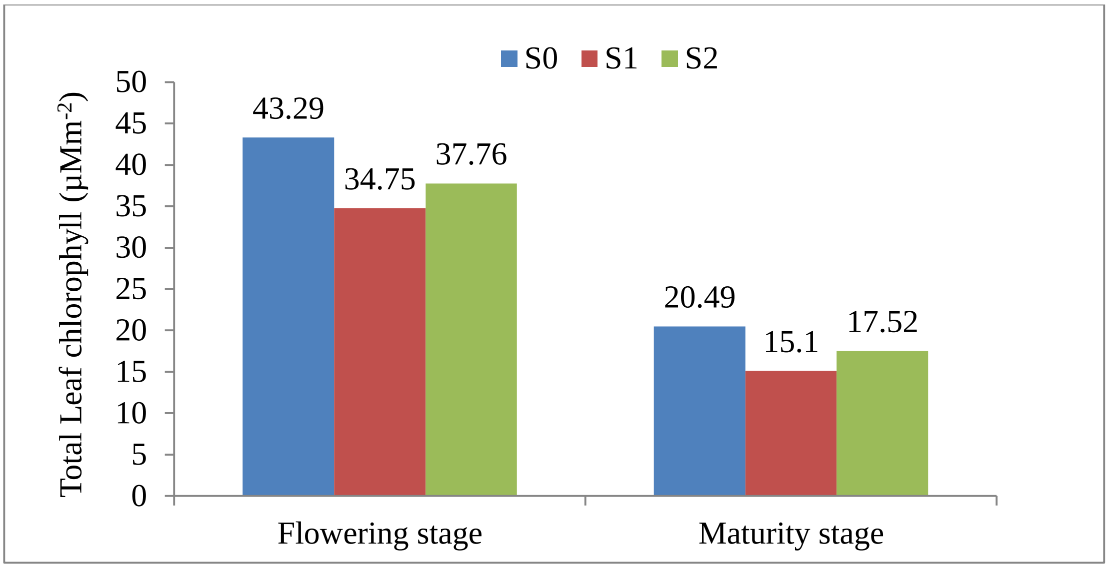

Figure 18. Effect of different level of drought stress on total leaf chlorophyll content of rice

S_0 = Control (normal irrigation), S_1 = Moderate drought stress (water withheld from flowering stage to season end), S_2 = Sever drought stress (water withheld from panicle initiation stage to season end)

4.9.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of salicylic acid and different level of drought stress had significant influence on total chlorophyll content (Table 8). The highest total chlorophyll content (49.17 and 25.14 µMm^{-2} at flowering and maturity stages, respectively) was with T_3S_0. The results recorded from T_0S_1 showed the lowest highest total chlorophyll content (30.02 and 11.15 µMm^{-2} at flowering and maturity stages, respectively).

Table 8. Interaction effect of salicylic acid and different level of drought stress on total leaf chlorophyll content of rice

Treatment combinations	Total leaf chlorophyll (µMm^{-2})	
	Flowering stage	Maturity stage
T_0S_0	37.580 ef	16.00 ef
T_0S_1	30.023 i	11.15 g
T_0S_2	33.667 gh	13.55 fg
T_1S_0	41.100 cd	19.05 cd
T_1S_1	32.350 hi	13.33 g
T_1S_2	36.033 fg	16.02 ef
T_2S_0	45.067 b	22.02 b
T_2S_1	36.333 fg	16.00 ef
T_2S_2	37.667 ef	19.00 cd
T_3S_0	49.446 a	25.14 a
T_3S_1	39.171 de	18.72 cd
T_3S_2	43.921 b	21.71 b
T_4S_0	43.257 bc	20.21 bc
T_4S_1	35.882 fg	16.31 def
T_4S_2	37.507 ef	17.31 cde
$LSD_{(0.05)}$	2.43	2.22
CV (%)	4.34	8.65

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.10. Root dry weight hill^{-1}

4.10.1 Effect of salicylic acid

Significant variation was observed by salicylic acid used in the present study in terms of root dry weight hill^{-1} (Table 9). The T_3 treatment showed the highest root dry weight hill^{-1} (5.23 g), which was statistically identical from other. The T_0 treatment showed the lowest number root dry weight hill^{-1} (3.17). Root dry weight increased with increasing doses of salicylic acid.

Table 9. Effect of salicylic acid on shoot and root dry weight, total dry weight and leaf area index of rice

Treatments	Root dry weight (g)	Shoot dry weight (g)	Total dry weight (g)
T_0	3.17d	15.83 d	19.00 d
T_1	3.88 c	17.67c	21.54 c
T_2	4.50 b	20.33b	24.83 b
T_3	5.23 a	23.67 a	28.90 a
T_4	4.34bc	19.91 b	24.26b
$LSD_{(0.05)}$	0.42	1.25	1.56
CV (%)	11.01	7.05	7.22

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.10.2 Effect of different level of drought stress

Significantly varied results were observed in terms of root dry weight hill^{-1} as influenced by different drought stress (Table 10). The highest root dry weight hill^{-1} was recorded by S_0 (5.09 g). The results obtained from S_1 showed the lowest dry weight hill^{-1} (3.35). The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}.

Table 10. Effect of different level of drought stress on shoot and root dry weight and total dry weight of rice

Treatment	Root dry weight (g)	Shoot dry weight (g)	Total dry weight (g)
S_0	5.09 a	22.78 a	27.87 a
S_1	3.35 c	16.5 8 c	19.93 c
S_2	4.23 b	19.08 b	23.32 b
$LSD_{(0.05)}$	0.36	1.05	1.31
CV (%)	11.01	7.05	7.22

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.10.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different of drought stress had significant influence on root dry weight hill^{-1} at different growth stages (Table 11). Results indicated that the highest root dry weight hill^{-1} (6.27) was with T_3S_0, which was closely followed by T_2S_0.The results recorded from T_0S_1 showed the lowest dry weight hill^{-1} (2.50 g). The results obtained from all other treatments at different growth stages showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}(Table 11)

Table 11. Interaction effect of salicylic acid and different level of drought stress shoot and root dry weight and total dry weight of rice

Treatment combinations	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)
T_0S_0	18.00 ef	4.00 de	22.00 efg
T_0S_1	14.00 h	2.50 g	16.50 j
T_0S_2	15.50 gh	3.00 fg	18.50 hij
T_1S_0	21.00 cd	4.50 cd	25.50 cd
T_1S_1	15.00 gh	3.00 fg	18.00 ij
T_1S_2	17.00 fg	4.13 de	21.13 fgh
T_2S_0	24.00 b	5.50 b	29.50 b
T_2S_1	17.00 fg	3.50 ef	20.50 ghi
T_2S_2	20.00 de	4.50 cd	24.50 de
T_3S_0	27.84 a	6.27 a	34.11a
T_3S_1	19.34 de	4.25 de	23.58 def
T_3S_2	23.84 b	5.17 bc	29.01 b
T_4S_0	23.08 bc	5.16 bc	28.24 bc
T_4S_1	17.58 efg	3.51ef	21.09 fghi
T_4S_2	19.08 def	4.36 cdf	23.44 defg
$LSD_{(0.05)}$	1.99	0.67	2.48
CV (%)	7.05	11.01	7.22

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.11 Shoot dry weight hill^{-1}

4.11.1 Effect of salicylic acid

Significant variation was observed by SA used in the present study in terms of shoot dry weight (Table 9). Results showed that T_3 showed the highest shoot dry weight plant^{-1} (23.67 g). The T_0 treatment showed the lowest number dry weight plant^{-1} (15.83 g). This results indicates that foliar application of SA at lower doses have positive effect on the dry matter production of BRRI dhan28 and the doses of SA up to 750 µMm^{-2} have no negative effect on the dry matter production. Dry mass production increased due to application of SA (Usharani *et al*., 2014).

4.11.2 Effect of different level of drought stress

Significantly varied results were observed in terms of shoot dry weight plant^{-1} as influenced by different level of drought stress (Table 10). The highest shoot dry weight plant^{-1} was recorded by S_0 (22.78 g). The results obtained from S_1 showed the lowest shoot dry weight plant^{-1} (16.58 g). The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}.

4.11.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on shoot dry weight hill^{-1} (Table 11). Results indicated that the highest shoot dry weight hill^{-1} (27.84) was with T_3S_0 which was closely followed by T_3S_2. The results recorded from T_0S_1 showed the lowest shoot dry weight hill^{-1} (14.00). The results obtained from all other treatments at different growth stages showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}.

4.12 .Total dry weight hill^{-1}

4.12.1 Effect of salicylic acid

Significant variation was observed by SA used in the present study in terms of total dry weight hill^{-1} (Table. 9). Results showed that the T_3 treatmentshowed the highest total dry weight hill^{-1} (28.90 g). ACI the T_0 showed the lowest total dry weight hill^{-1} (27.87 g). This results indicate that foliar application of SA at moderate doses have positive effect on the total dry matter production of BRRI dhan28 and the doses of SA up to 750 µMm^{-2} have no negative effect on the dry matter production. Dry mass production increased due to application of SA (Usharani *et al*., 2014).

4.12.2 Effect of different level of drought stress

Significantly varied results were observed in terms of total dry weight hill^{-1} as influenced by different drought stress. The highest total dry weight hill^{-1} (Table. 10) was recorded by S_0 (27.87 g) . The results obtained from S_1 showed the lowest total dry weight hill^{-1} (19.93 g). The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}. The S_2 gave intermediate level result compared to highest and lowest total dry weight hill^{-1}.

4.12.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on total dry weight hill^{-1} (Table 11). Results indicated that the highest total dry weight hill^{-1} (34.11g) was with T_3S_0 which was closely followed by T_2S_0 and T_3S_2. The results recorded from T_0S_1 showed the lowest total dry weight hill^{-1} (16.50 g). The results obtained from all other treatments showed significantly different results compared to the highest and the lowest result of dry weight hill^{-1}(Table 11)

4.13 Panicles hill^{-1}

4.13.1 Effect of salicylic acid

Number of panicles hill^{-1} was significantly influenced by exogenous application of SA used in the present study (Table 12). Results showed that T_3 treatmentshowed the highest number of panicles hill^{-1} (17.22) which were statistically identically with other. T_0 showed the lowest number of panicles hill^{-1} (9.00).

4.13.2 Effect of different level of drought stress

Different level of drought stress had significant effect on number of panicles hill^{-1} among the three drought stress of *boro* rice (Table 13). Results showed that the highest number of panicles hill^{-1} was recorded by S_0 (16.42). The results obtained from S_1 showed the lowest number of panicles hill^{-1} (9.48).

Table 12. Effect of salicylic acid on panicle/hill, filled grain and unfilled grain/Panicle of rice

Treatment	Panicle/hill (No.)	Filled grain/Panicle (No.)	Unfilled grain/Panicle (No.)
T_0	9.00 d	25.33 d	17.00 a
T_1	11.50 c	31.33 c	14.67 b
T_2	14.83b	39.33 b	13.00 c
T_3	17.22 a	47.26 a	12.61c
T_4	12.91c	37.48b	14.28 b
$LSD_{(0.05)}$	1.33	3.19	0.85
CV (%)	11.13	9.69	6.49

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

Table 13. Effect of different level of drought stress on filled grain and unfilled grains panicle^{-1} of rice

Treatments	Panicles hill^{-1}	Filled spikelet panicle^{-1}	Unfilled spikelet panicle^{-1}
S_0	16.42 a	44.40 a	11.84 c
S_1	9.48 c	27.70 c	16.74 a
S_2	13.38 b	36.35 b	14.34 b
$LSD_{(0.05)}$	1.12	2.68	0.71
CV (%)	11.13	9.69	6.49

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.13.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on number of panicles hill^{-1} (Table 14). Results indicated that the highest number of panicles hill^{-1} (20.64) was with T_3S_0 which was statistically identical with other and closely followed by T_2S_0 at the time of harvest. The results recorded from T_0S_1

showed the lowest number of panicles hill^{-1} (6.00). The results obtained from all other treatments combinations was significantly different compared to the highest and the lowest number of panicles hill^{-1}.

Table 14. Interaction effect of salicylic acid and different level of drought stress on filled grain and unfilled grain panicle^{-1} of rice

Treatment combinations	Panicles hill^{-1}	Filled grains panicle^{-1}	Unfilled grains panicle^{-1}
T_0S_0	12.00 fg	30.00 ef	14.00 cd
T_0S_1	6.00 k	20.00 h	20.00 a
T_0S_2	9.00 ij	26.00 fg	17.00 b
T_1S_0	15.00 de	38.00 c	12.00 efg
T_1S_1	8.00 jk	24.00 gh	17.00 b
T_1S_2	11.50 fgh	32.00 de	15.00 c
T_2S_0	18.00 b	49.00 b	11.00 fg
T_2S_1	11.00 ghi	30.00 ef	15.00 c
T_2S_2	15.50 cde	39.00 c	13.00 de
T_3S_0	20.64 a	58.51 a	10.78 g
T_3S_1	13.29 ef	36.01 cd	14.78 c
T_3S_2	17.72 bc	47.26 b	12.28 ef
T_4S_0	16.46 bcd	46.48 b	11.44 efg
T_4S_1	9.13 hij	28.48 efg	16.94 b
T_4S_2	13.16 efg	37.48 cd	14.44 cd
$LSD_{(0.05)}$		5.07	1.35
CV (%)	11.13	9.69	6.49

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.14. Number of filled grains panicle^{-1}

4.14.1 Effect of salicylic acid

Number of filled grains panicle^{-1} was influenced by SA used in the present study (Table 12). Results showed that T_3 had the highest number of filled grains panicle^{-1} (47.26) and T_0 showed the lowest number of filled grains panicle^{-1} (25.33). This result suggests that foliar application of SA could help to increase the filled grain yield of

BRRI dhan28. Usharani *et al*., (2014) showed that filled grains panicle^{-1} increased significantly by the application of SA.

4.14.2 Effect of different level of drought stress

Different level of drought stress had significant effect on number of filled grains panicle^{-1} (Table 13). Results showed that the highest number of filled grains panicle^{-1} was recorded by S_0 (44.40) where the lowest (27.70) was obtained from S_1. The results obtained from S_2 showed medium result compared to the highest and the lowest number of filled grains panicle^{-1}.

4.14.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on number of filled grains panicle^{-1} (Table 14). Results indicated that the highest number of grains panicle^{-1} (58.51) was with T_3S_0 which was significantly different from all other treatment combinations. On the other hand the lowest result was recorded from T_0S_1 (20.00) which were also significantly different from all other treatment combinations. The results obtained from all other treatments combinations was significantly different compared to the highest and the lowest number of grains panicle^{-1}.

4.15 Number of unfilled grains panicle^{-1}

4.15.1 Effect of salicylic acid

Number of unfilled grains panicle^{-1} was significantly influenced by SA used in the present study (Table 12). Results showed that T_0 showed the highest number of unfilled grains panicle^{-1} (17.00) and T_3 showed the lowest number of unfilled grains panicle^{-1} (12.61), which was statistically similar with T_2. These results showed that number of unfilled grains panicle^{-1} was decreased with increasing levels of SA as foliar application. Mohammed (2011) reported that number of unfilled grains panicle^{-1} was decreased due to the application of SA.

4.15.2 Effect of different level of drought stress

Different level of drought stress had significant effect on number of unfilled grains panicle^{-1} (Table 13). Results showed that the highest number of filled grains panicle^{-1}

was recorded by S_1 (16.74) where the lowest (11.84) was obtained from S_0. The results obtained from S_2 showed medium result compared to the highest and the lowest number of filled grains panicle^{-1}. The results are in agreement with the findings of Hossain (2001), Yambao and Ingram (1988), Begum (1990) and Islam *et al*. (1994) who stated that the increased unfilled grains panicle^{-1} is due to water stress condition.

4.15.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on number of unfilled grains panicle^{-1} (Table 14). Results indicated that the highest number of unfilled grains panicle^{-1} (20.00) was with T_0S_1 which was significantly different from all other treatment combinations. On the other hand the lowest result was recorded from T_3S_0 (10.78) which were also significantly different from all other treatment combinations. The results obtained from all other treatment combinations was significantly different compared to the highest and the lowest number of grains panicle^{-1}.

4.16 Weight of 1000 grains

4.16.1 Effect of salicylic acid

Weight of 1000 grains was influenced by SA used in the present study (Table 15). Results showed that T_3 produced the highest 1000 grain weight (19.85 g) where T_0 showed the lowest 1000 grain weight (17.133 g). Ibrahim *et al*., (2014) showed 1000 grain weight increased significantly by the application of SA.

4.16.2 Effect of different level of drought stress

Different level of drought stress had significant effect on 1000 grain weight (Table 16). Results showed that the highest 1000 grain weigh was recorded by S_0 (19.51 g) where the lowest (17.54 g) was obtained from S_1. The results obtained from S_2 showed medium result compared to the highest and the lowest 1000 grain weight. The results are in agreement with the findings of Rahman *et al*. (2002) and Zubaer *et al*. (2007) who observed that water stress reduced grain weight in different varieties of rice.

4.16.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on 1000 grains weight (Table 17). Results indicated that the highest 1000 grains weight (20.89 g) was with T_3S_0 which was closely followed by T_2S_0. On the other hand the lowest result was recorded from T_0S_1 (16.20 g). The results obtained from all other treatments combinations was significantly different compared to the highest and the lowest 1000 grains weight.

Table 15. Effect of salicylic acid on yield and yield contributing character of rice

Treatments	1000-grains weight (g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)	Harvest index (%)
T_0	17.133 d	9.32 c	19.32 a	32.45 c
T_1	18.078 c	9.60 bc	18.76 ab	33.75 bc
T_2	19.189 b	10.05 b	18.30 bc	35.35 b
T_3	19.84 a	11.03 a	17.86 c	38.15 a
T_4	18.33 c	9.82 bc	18.32 abc	34.77 b
$LSD_{(0.05)}$	0.46	0.56	0.86	1.80
CV (%)	2.73	6.20	5.10	5.68

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

Table 16. Effect of different level of drought stress on yield and yield contributing character of rice

Treatments	1000-grain weight (g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)	Harvest index (%)
S_0	19.515 a	11.21 a	17.84 b	38.58 a
S_1	17.537 c	8.89 c	19.15 a	31.63 c
S_2	18.499 b	9.78 b	18.56 a	34.49 b
$LSD_{(0.05)}$	0.39	0.47	0.72	1.52
CV (%)	2.73	6.20	5.10	5.68

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

Table 17. Interaction effect of salicylic acid and different level of drought stress on yield and yield contributing character of rice

Treatment combinations	1000-grains weight (g)	Grain yield hill^{-1} (g)	Straw yield hill^{-1} (g)	Harvest index (%)
T_0S_0	18.100 ef	10.80 bc	18.86 abc	36.422 bcde
T_0S_1	16.20 h	7.65 g	19.96 a	27.72 h
T_0S_2	17.10 g	9.49 e	19.13 ab	33.21 efg
T_1S_0	19.13 cd	10.75 bc	18.23 bcd	37.02 bcd
T_1S_1	17.06 g	8.41 fg	19.16 ab	30.49 gh
T_1S_2	18.03 f	9.63 de	18.90 abc	33.74 defg
T_2S_0	20.23 ab	11.25 ab	17.46 cd	39.09 ab
T_2S_1	18.13 ef	9.02 ef	18.86 abc	32.31fg
T_2S_2	19.20 cd	9.86 cde	18.56 abc	34.65 cdef
T_3S_0	20.89 a	12.01 a	16.98 d	41.39 a
T_3S_1	18.86 de	10.51 bcd	18.66 abc	35.99 bcde
T_3S_2	19.79 bc	10.54 bcd	17.93bcd	37.08 bc
T_4S_0	19.22 cd	11.24 ab	17.62 bcd	38.96 ab
T_4S_1	17.42 fg	8.85 ef	19.07 abc	31.61fg
T_4S_2	18.37 def	9.35 ef	18.27 abcd	33.74 cdefg
$LSD_{(0.05)}$	0.73	0.89	1.37	2.87
CV (%)	2.73	6.20	5.10	5.68

In a column, means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

4.17 Grain yield

4.17.1 Effect of salicylic acid

Grain yield was significantly influenced by salicylic acid used in the present study (Table 15). Results showed that T_3 treatment showed the highest grain yield (11.03 g hill^{-1}) where T_0 showed the lowest grain yield (9.32 g hill^{-1}). However foliar application of salicylic acid might be helpful to recover the yield gap, increasing the grain yield and reduction of insect-pest infestation. Dry mass production increased due to application of SA (Usharani *et al*., 2014 and Mohammed, 2011).

4.17.2 Effect of different level of drought stress

Different level of drought stress had significant effect on grain yield (Table 16). Results showed that the highest grain yield was recorded by S_0 (11.24 g hill^{-1}) where the lowest (8.89 g hill^{-1}) was obtained from S_1.

4.17.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on grain yield (Table 17). Results indicated that the highest grain yield (12.02 g hill^{-1}) was with T_3S_0. Again, the lowest result was recorded from T_0S_1 (7.66 g hill^{-1}) The results obtained from the rest of the treatment combinations showed intermediate level of grain yield compared to the highest and the lowest grain yield.

4.18 Straw yield

4.18.1 Effect of salicylic acid

Straw yield was significantly influenced by SA used in the present study (Table 15). Results showed that T_3 produced the highest straw yield (19.32 g hill^{-1}) and the lowest straw yield (17.86 g hill^{-1}) was achieved by T_0. Usharani *et al*. (2014) showed highest straw yield from the application of SA.

4.18.2 Effect of different level of drought stress

Different level of drought stress had significant effect on straw yield among (Table 16). Results showed that the highest straw yield was recorded by S_1 (19.15 kg hill^{-1}), which was statistically similar with S_2 where the lowest (17.84 kg hill^{-1}) was obtained from S_0.

4.18.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on straw yield (Table 17). Results indicated that the highest straw yield (19.97 g hill^{-1}) was with T_0S_1. The lowest result was recorded from T_3S_0 (16.99 g hill^{-1}) which was significantly different from all other treatments. The results obtained from the rest of the treatment combinations showed intermediate level of straw yield compared to highest and lowest straw yield.

4.19 Harvest index

4.19.1 Effect of salicylic acid

Harvest index was influenced by SA used in the present study (Table 15). Results showed that T_3 produced the highest Harvest index (38.15%) where the lowest harvest index (32.35%) was achieved by T_0.

4.19.2 Effect of different level of drought stress

Different level of drought stress had significant effect on harvest index (Table 16). Results showed that the highest harvest index was recorded by S_0 (38.58%) where the lowest (31.63%) was obtained from S_1.

4.19.3 Interaction effect of salicylic acid and different level of drought stress

Interaction effect of SA and different level of drought stress had significant influence on harvest index (Table 17). Results indicated that the highest harvest index (41.39%) was with T_3S_0. the lowest result was recorded from T_0S_1 (27.72%) The results obtained from the rest of the treatment combinations showed intermediate level of harvest index value compared to the highest and the lowest harvest index result.

CHAPTER V
SUMMARY AND CONCLUSION

The experiment was conducted at the Central research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from November 2017 to May, 2018 to know the effect of exogenous application of SA on mitigation of drought stress in *boro* rice. The experiment comprised of five different concentration of salicylic acid viz. T_0 = Without exogenous application of SA, exogenous application of SA @ 250 μMm^{-2}, Exognous application of SA @ 500 μMm^{-2}, exogenous application of SA @ 750 μMm^{-2}, exogenous application of SA @ 1000 μMm^{-2} and three level of drought stress, S_0 = control (normal irrigation), S_1 = moderate drought stress (water withheld from flowering stage to season end), S_2 = sever drought stress (water withheld from Panicle initiation stage to season end). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

Significant variation was recorded for data on growth, yield and yield contributing parameters of experimental materials. Data was collected on plant height (cm), number of leaves hill^{-1}, number of tillers hill^{-1}, Leaf area index, Relative water content (%), Leaf membrane stability index, Flag leaf chlorophyll content (μMm^{-2}), number of panicle , number of filled grain, number of unfilled grain, 1000 seed weight, 1000 grains weight (g), grain yield, and straw yield and harvest index (%).

Interaction effect of salicylic acid and different level of drought stress was significantly influenced in all parameter. Results showed that the highest plant height (85.72 and 97.67 cm at flowering and maturity stages, respectively), number of leaves hill^{-1} (106.12 and 69.80 at flowering and maturity stages, respectively), number of tillers hill^{-1} (17.14 and 36.11 at flowering and maturity stages, respectively), shoot dry weight hill^{-1} (27.84), root dry weight hill^{-1} (6.27), total dry weight hill^{-1} (34.11 g), leaf area index (5.13), relative water content (124.79 and 231.73 % at flowering and maturity stages, respectively), leaf membrane stability index (29.72 and 5.48 at flowering and maturity stages, respectively), flag leaf chlorophyll content (49.17 and 25.14 $\mu M\ m^{-2}$at flowering and maturity stages, respectively), number of filled grains panicle^{-1} (58.51), 1000 grains weight (20.89 g) were obtained from foliar application of SA @ 750 μMm^{-2} with normal irrigation (T_3S_0). The maximum grain yield (12.02 g $hill^{-1}$) was with T_3S_0. Results indicated that the highest straw yield (19.97 g $hill^{-1}$) was with T_0S_1. The highest harvest index (41.39%) was with T_3S_0.

Significant influence was remarked in terms of all parameter with different concentration of salicylic acid of boro rice. Results showed that the highest plant height (80.15 and 90.85 cm at flowering and maturity stages, respectively), number of leaves $hill^{-1}$ (95.01 and 63.16 at flowering and maturity stages, respectively), number of tillers $hill^{-1}$ (13.31 and 29.72 at flowering and at maturity stages, respectively), shoot dry weight $hill^{-1}$ (23.67 g), root dry weight $hill^{-1}$ (5.23 g), total dry weight $hill^{-1}$ (28.90 g), leaf area index (4.78), relative water content (112.66 and 206.37 % at flowering and maturity stages, respectively), leaf membrane stability index (26.41 and 4.18 at flowering and maturity stages, respectively), flag leaf chlorophyll content (44.18 and 21.86 μMm^{-2} at flowering and maturity stages)., number of filled grains $panicle^{-1}$ (47.26), 1000 grains weight (19.85 g) were obtained from foliar application of SA @ 750 μMm^{-2} (T_3). The maximum grain yield (11.03 kg $hill^{-1}$) was obtained from T_3 treatment (foliar application of SA @ 750 μMm^{-2}). The treatment T_3 gave the highest straw yield (19.32 g $hill^{-1}$) and harvest index (38.16%).

Significant influence was remarked in terms of all parameter with different level of drought stress of *boro* rice. Results showed that the highest plant height (80.26 cm and 92.02 cm at flowering and maturity stages, respectively), number of leaves $hill^{-1}$ (93.88 and 62.74 at flowering and maturity stages, respectively), number of tillers $hill^{-1}$ (13.97 and 29.8 at flowering and maturity stages, respectively), root dry weight $hill^{-1}$ (5.09 g), dry weight $hill^{-1}$ (27.87 g), leaf area index (4.73), relative water content (107.44 and 201.16 % at flowering and maturity stages, respectively), leaf membrane stability index 25.69 and 4.43 % at flowering and maturity stages, respectively), flag leaf chlorophyll content (43.29 and 20.48 μMm^{-2} at flowering and maturity stages, respectively), number of filled grains $panicle^{-1}$ (44.0), 1000 grains weight (19.51 g) was obtained from S_0 (Control normal irrigation). The maximum grain yield (11.24 g $hill^{-1}$) was obtained from S_0 treatment normal irrigation). The treatment (cotrol) gave the highest straw yield (19.15 g $hill^{-1}$) and harvest index (38.58%).

From the above summary of the study, it can be concluded that growth and yield contributing parameters are positively correlated with salicylic acid and different level of drought stress. However, BRRI dhan28 planted with severe drought stress would be mitigated (partially recovered) by the application of SA @750 μMm^{-2}

Recommendation

Further study should be require regarding the effect of SA on drought stress in different growth stages of rice to elucidate the timing and dose of application of SA as well as severity of drought stress.

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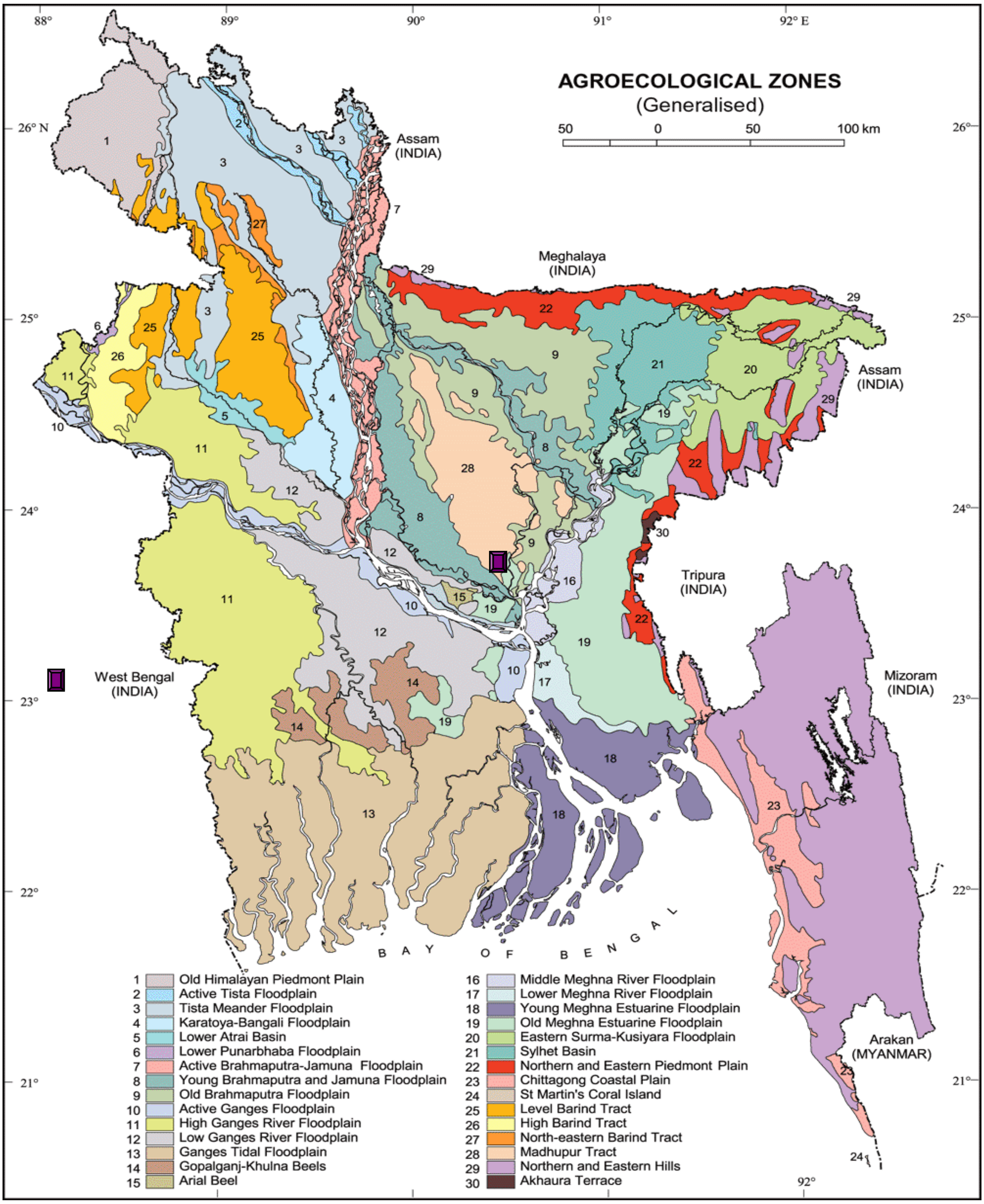
APPENDICES

Appendix I: Map showing the experimental sites under study



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

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Field laboratory, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	Medium hHigh land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI),