ALLEVIATION OF SALT STRESS IN WHEAT WITH SALICYLIC ACID

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CERTIFICATE

This is to certify that the thesis entitled **"ALLEVIATION OF SALT STRESS IN WHEAT WITH SALICYLIC ACID"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRICULTURAL BOTANY,** embodies the results of a piece of *bona fide* research work carried out by **SAYED ABDUL AKHER,** Registration. No. **14-06312** under my supervision and guidance. No part of this 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, 2015
Dhaka, Bangladesh

(Prof. Dr. Mohammad Mahbub Islam)
Supervisor

DEDICATED

TO

MY

BELOVED PARENTS

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ABSTRACT

A pot experiment was conducted in the farm of Sher-e-Bangla Agricultural University, Dhaka, during Rabi season, November 2014 to March 2015 to examine the role of salicylic acid on alleviation of salt stress in wheat. In this experiment, the treatment consisted of four different salinity levels *viz*. S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} soil ≈ 3-4 dSm^{-1}, S_2 = 6.0 g NaCl kg^{-1} soil ≈ 7-8 dSm^{-1}, S_3 = 9.0 g NaCl kg^{-1} soil ≈ 11-12 dSm^{-1} and three different levels of salicylic acid *viz*. A_0 = 0 mM, A_1= 0.2 mM and A_2 = 0.4 mM. The experiment was laid out in two factors Randomized Complete Block Design (RCBD) with four replications. The total treatment combinations were 12 (4x3). Results of the experiment showed a significant variation among the treatments in respect of most of the studied parameters. The morpho-physiology, yield contributing characters and yield of wheat are affected by different levels of salinity. The higher levels of salinity showed greater reduction of growth, development and yield component to control or without NaCl. The morphological characters such as plant height, leaf number, both total tiller and effective tiller number $plant^{-1}$; physiological parameter membrane stability, fresh and dry weight $plant^{-1}$, yield contributing characters such as number of spikelet $spike^{-1}$, number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000 grain weight and yield of wheat significantly decreased due to salinity. Separately exogenous application of SA improved the morpho-physiology, yield contributing characters and yield of wheat. The foliar application of SA increased plant height, leaf number, both total tiller and effective tiller number $plant^{-1}$, fresh and dry weight $plant^{-1}$, number of spikelet $spike^{-1}$, number of grains $spike^{-1}$, grain weight $spike^{-1}$, 1000 grain weight and yield of wheat. At salt stress, the SPAD value which indicates chlorophyll content did not show any significant difference due to salicylic acid. These results indicate that salicylic acid has positive effect on reproductive attributes of wheat. The interaction between different levels of salinity and salicylic acid influenced on almost all morpho-physiological parameters and yield contributing characters and grain yield of wheat. The SPAD value of leaf of wheat did not show any difference with interaction effect of salinity and salicylic acid. The highest grain yields (1.55 t ha^{-1}) were recorded at S_0A_2 (Without Salt + 0.4 mM SA) treatment combination which did not show any difference with S_0A_0 (Without Salt+ Without SA) and S_0A_1 (Without Salt + 0.2 mM SA). But the grain yield was gradually decreased with the increasing level of salinity. The application of SA increased the grain yield differently according to the levels of salinity. The minimum grain yields were found 1.14 t ha^{-1}, 1.07 t ha^{-1} and 0.26 t ha^{-1} at 3-4 dSm^{-1}, 7-8 dSm^{-1} and 11-12 dSm^{-1} NaCl respectively. These yields were increased with SA (0.4 mM) from 1.14 to 1.32 t ha^{-1}, 1.07 to 1.14 t ha^{-1} and 0.26 to 0.31 t ha^{-1} at 3-4 dSm^{-1}, 7-8 dSm^{-1} and 11-12 dSm^{-1} NaCl respectively. These results suggest that SA can alleviate the detrimental effects of salinity to increase the grain yield of wheat.

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop and ranks first globally and second in Bangladesh both in terms of production and acreage (Anonymous, 2010). It is a staple food crop for more than one third of the world population (Shirazi *et al*., 2001). In Bangladesh, the area under wheat cultivation during 2013-2014 was about 1061602 acres producing 1302998 M. tons with an average yield of 1233 kg acre^{-1} (BBS, 2014).

Various environmental stresses such as drought, cold, salinity causes heavy losses in agricultural production due to disruption in physiological and biochemical processes in plant. Salinity is major abiotic stressors which hinder crop production. It creates and adversely impacts the socio-economic condition of many developing countries including Bangladesh. In Bangladesh, over 30% of the net cultivable areas lie in the coastal zone close to the Bay of Bengal of which approximately 53% are affected by varying degrees of salinity (Haque, 2006). It has been reported that more than 1 million hectares of the coastal areas have been seriously affected by salinity (Rahman, 2007). Ali (2011) showed that the salt-affected areas in the coastal region of Bangladesh increased sharply, by 26.71% , to 950,780 hectares in 2009 from 750,350 hectares in 1973. Agricultural land use in salt affected areas is very poor in respect of crop production (Petersen and Shireen, 2010). Most of the high yielding salt sensitive crop might not be suitable for cultivation in the existing cropping pattern.

Wheat is cultivated over a wide range of environments, because of wide adaptation to diverse environmental conditions. It is a moderately salt-tolerant crop (Moud *et al*., 2008). Wheat crop is mainly cultivated in the north and north-west part of Bangladesh. A vast area of cultivable land of the coastal region remains fallow (seasonal or complete) and the dominant cropping pattern of there is fallow-aman-fallow. Introduction of wheat into the existing cropping pattern in the saline soil may become a worthy effort to utilize these lands to meet up the food and nutritional balance of the over increasing population of Bangladesh.

Salinity reduces the growth of wheat plant by reducing the plants ability to absorb water from soil. Salinity also disturbs the physiology of plants by changing the metabolism of plants (Garg *et al*., 2002). Wheat under saline conditions increases the concentration of proline and sugar resulting in significant increase of electrolyte leakage at 10 and 15 dSm^{-1} (Khatkar *et al*., 2000). It has been reported that increase in salinity concentration brings about decrease in relative growth rate, net assimilation rate, K^+ and Ca^{2+} concentration, and grain yield of wheat, but causes an increase in Na^+ and Cl^- levels, this might be due to increase in Na^+/K^+ ratio in grain and straw at tillering stage (Chhipa *et al*., 1995; El-Hendawy *et al*., 2005). Salinity affects wheat seedling growth by changing phytohormone levels (Shakirova *et al*., 2003). Furthermore, salinity induces reduction in photosynthetic rate and stomatal conductance in wheat. Adding more NaCl increases the action of superoxide dismutase and peroxidase and reduces the transpiration rate in *Triticum aestivum* (Sharma *et al*., 2005). Moreover, increased salinity induces a considerable reduction in height, number of fertile tillers and dry weight of shoots in wheat (Iqbal *et al*., 2005). Exposing wheat to salt stress leads to decrease in cell growth which causes reduction in leaf area, biomass and yield because many physiological processes are affected by salinity (Asadi *et al*., 2007). High salinity concentration 150 mM NaCl induces leaf senescence or reduction of leaf protein in wheat, consequently accelerating oxygen radicals and hydrogen peroxide production in leaves (Hameed *et al*., 2008). Salinity also induces increases in respiration of wheat seedlings due to markedly consuming carbohydrates for maintenance of plant growth (Moud *et al*., 2008). Harris *et al*. (2010) emphasized that, the low salt concentration 15 mM was able to decrease transpiration rate in seedlings of wheat. These results are in line with Perveen *et al*., (2010) who demonstrated that the reduction of net CO_2 assimilation rate, stomatal conductance and transpiration rate in wheat under salt stress (150 mM).

The salicylic acid (SA), an endogenous plant growth regulator has been found to generate a wide range of metabolic and physiological responses in plants thereby affecting their growth and development (Hayat *et al*., 2010). The role of SA in defense mechanism to alleviate salt stress in plants (Afzal *et al*., 2006; Hussein *et al*., 2007) were observed. The ameliorative effects of SA have been well documented including salt tolerance in many crops such as bean (Azooz, 2009; El-Tayeb, 2005; Gunes *et. al*, 2007 and Stevens *et al*., 2006).

The exogenous application of SA enhanced the photosynthetic rate and also maintain the stability of membranes, thereby improved the growth of salinity stressed barley plants (El-Tayeb, 2005). An enhanced tolerance against salinity stress was observed in wheat seedlings raised from the grains soaked in salicylic acid (Hamada and Al-Hakimi 2001). The detrimental effects of high salts on the early growth of wheat seedlings may be alleviated by treating seeds with the proper concentration of a suitable hormone such Salicylic acid (Shakirova and Bezrukova, 1997). Wheat seedlings accumulate large amount of proline under salinity stress which was further increased when salicylic acid was applied exogenously, thereby alleviating the deleterious effects of salinity (Shakirova *et al.,* 2003). Further, the treatment also lowered the level of active oxygen species and therefore the activities of SOD and peroxidase (POX) were also lowered in the roots of young wheat seedlings (Shakirova *et al*., 2003). The pre-sowing soaking treatment of seeds with SA positively affected the osmotic potential, shoot and root dry mass, Na^+/K^+ ratio and contents of photosynthetic pigments in wheat seedlings, under saline and non- saline conditions (Kaydan *et al*., 2007).

In perspective to this scenario, the present investigation was carried out to evaluate the effectiveness of SA on improving wheat salt tolerance in order to spread saline agriculture through wheat production.

Objectives of the research

Considering the fact described above, the present work was undertaken to achieve the following objectives-

1. To investigate the independent effects of salinity and salicylic acid on changes of morpho-physiology and yield of wheat.

2. To investigate the interaction effects of salinity and salicylic acid on changes of morpho-physiology and yield of wheat.

3. To find out the best combination/combinations between different levels of salinity and salicylic acid on alleviation of salt stress with SA of wheat.

CHAPTER II

REVIEW OF LITERATURE

Salinity is one of the most important abiotic stresses limiting crop production in arid and semiarid regions (Saboora, 2006) and it is a great problem in the coastal region of Bangladesh, where a vast area remains fallow for long time. Wheat is an important cereal crops in Bangladesh and it is a great source of carbohydrate and protein. The scientists of Bangladesh are conducting different experiments to adopt different crops in the saline area; wheat is one of them. Very limited research works have been conducted to adapt wheat in the saline area of Bangladesh. An attempt has been made to find out the performance of wheat at different levels of salinity as well as to find out the possible mitigation ways by using salicylic acid in the saline stressed wheat plants. To facilitate the research works different literatures have been reviewed in this chapter under the following headings.

Effect of salinity on morphological characters of plant

Alaa El-Din Sayed Ewase (2013) conducted a pot experiment to observe the effect of salinity stress on plants growth of Coriander (*Coriandrum sativum* L.). He used four treatments of different concentrations of NaCl namely 0, 1000, 2000, 3000 and 4000 ppm. The Obtained results showed that plant length, number of leaves, roots number and length were reduced by increasing the NaCl concentration and Coriander plants were found to resist salinity up to the concentration of 3000 ppm NaCl only.

Milne (2012) studied on the effects of 30 and 60 mM NaCl on Lettuce (*Lactuca sativa* L.), grown in soilless culture, with additions of 0, 1, 2 and 4 mM Si was evaluated. Height, leaf number, weight, chlorophyll content and elemental analysis of plants were examined.

Saberi *et al.* (2011) conducted a pot experiment where two forage sorghum varieties (Speed feed and KFS4) were grown under salinity levels of 0, 5, 10 and 15 dSm^{-1}. Leaf area of plants were also reduced in response to salinity and decreasing soil water availability, while the suppressive effect was magnified under the combined effect of the two factors. Salinity and water stress significantly affected the total leaf area of ratoon crop. The maximum total leaf area was obtained in the control treatment but with increasing salinity and infrequent irrigation, this parameter was found to decrease. Maximum leaf area of 1167 mm^2 $plant^{-1}$ was attained in plants with normal irrigation, without water stress. Under effects of salinity 5, 10 and 15 dSm^{-1} the leaf area was reduced by 7, 12 and 17%, respectively.

Nawaz *et al.* (2010) reported that applications of salt in the growth medium caused reduction in shoot length of sorghum cultivars. Under saline conditions 50 mM proline was more effective to reduce the effect of NaCl than 100 mM proline in both cultivars. Proline level 50 mM showed 26.58% and 11.78% increased shoot length as compared to NaCl stresses plants. However, high concentration of proline (100 mM) was not so much effective as compared to low concentration i.e. 50 mM.

Jafari *et al.* (2009) studied the interactive effects of salinity, calcium and potassium on physio-morphological traits of sorghum (*Sorghum biclolor* L.) in a green-house experiment. Treatments included 4 levels of NaCl (0, 80, 160, and 240 mM NaCl), 2 levels of $CaCl_2$ (0 and 20 mM), and 2 levels of KCl (0 and 20 mM). Salinity substantially reduced the plant growth as reflected by a decrease in the plant height, shoot and root weight.

Jampeetong and Brix (2009) and Gorai *et al.* (2010) reported that, various plant growths and development processes viz. seed germination, seedling growth, flowering and fruiting are adversely affected by salinity, resulting in reduced yield and quality.

BINA (2008) studied the screening of wheat varieties for growth and yield attributes contributing to salinity tolerance and reported that wheat varieties of high yielding and tolerant group recorded a higher value of number of effective tillers $plant^{-l}$.

Liu *et al.* (2008) reported significant reduction in the dry biomass of halophyte *Suaeda salsa* when exposed to different concentration of NaCl under different water regimes.

Munns and Tester (2008) observed that osmotic effect, which develops due to increasing salt concentration in the root medium, is a primary contributor in growth reduction in the initial stages of plant growth. This stage can be characterized by reduction in generation of new leaves, leaf expansion, development of lateral buds leading to fewer braches or lateral shoots formation in plants.

Memon *et al.* (2007) conducted a pot experiment on silty clay loam soil at Sindh Agriculture University, in Tando Jam, Pakistan. Sarokartuho variety of Sorghum (*Sorghum bicolor* L.) was continuously irrigated with fresh (control) and marginally to slightly saline EC 2, 3, 4 and 5 (dSm^{-1}) waters. Increasing water salinity progressively decreased plant height and fodder yield (fresh and dry weight) per plant.

Mortazainezhad *et al.* (2006) had observed that tiller number decreased with increasing salinity levels imposed at all growth stages in rice. Soil salinity affects the growth of rice plant. But the degree of deleterious effect may vary on the growth stages of plant. During germination rice is tolerant, but it becomes very sensitive during the early seedling stage. Similar result was also reported by many workers in rice (Linghe *et al.*, 2000; Burman *et al.*, 2002; Weon Young *et al.*, 2003; Islam, 2004; Rashid, 2005; Karim, 2007).

Munns (2005); Munns and Tester (2008) reported that salt-induced osmotic stress is the major reason of growth reduction at initial stage of salt stress, while at later stages accumulation of Na^+ occurs in the leaves and reduces plant growth.

Parida and Das (2005) observed salt stress affects some major processes such as root/shoot dry weight and Na^+/K^+ ratio in root and shoot.

Sixto *et al.* (2005) stated that depending on increasing salinity levels, decrease in vegetative growth parameters has been observed in plants. Decrease in root, stem and shoot developments, fresh & dry stem and root weights; leaf area and number and yield have been observed in plants subject to salinity stress.

Ali (2004) conducted a research on Salt tolerance in eighteen advanced rice genotypes was studied under an artificially salinized (EC= 8.5 dSm^{-1}) soil conditions after 90 days of transplanting. The results showed that the yield per plant, and number of productive tillers, panicle length and number of primary braches per panicle of all the genotypes were reduced by salinity.

Islam (2004) conducted a pot experiment to study the effect of salinity (3, 6, 9, 12 and 15 dSm^{-1}) on growth and development of rice under induced salinity condition and observed that number of leaves decreased with the increased salinity level. Similar result was also observed by Rashid (2005) in rice.

Netondo *et al.* (2004) conducted an experiment where sorghum plants were grown in sand culture under controlled greenhouse conditions. The NaCl concentrations in complete nutrient solution were 0 (control), 50, 100, 150, 200, and 250 mM. Salinity significantly reduced leaf area by about 86% for both varieties of sorghum and these decreases were similar for the two sorghum varieties.

Çiçek and Çakirlar (2002) observed salt stress caused a significant decrease in shoot length, fresh and dry weights of shoot and leaf area of both cultivars with the increase of stress treatments.

Javaid *et al.* (2002) investigated the salinity effect (0, 20, 50 and 75 mM NaCl) on plant height in four rice variety and reported that salinity affects the morphological characters of the studied plants and plant height decreased with increased salinity levels.

Javaid *et al.* (2002) investigated the salinity effect (0, 20, 50 and 75 mM NaCl) on plant height, stem diameter, TDM, leaf number and leaf area in four *Brassica* species and reported that salinity affected the morphological characters of the studied plants and leaf number as well as leaf area decreased with increased salinity levels.

Angrish *et al.* (2001) conducted a pot experiment and observed that increasing levels of chloride (0-12 dSm^{-1}) and sulfate salinity decreased leaf number of wheat plants. Similarly, Khan *et al.* (1997) reported that leaf number and leaf area were seriously decreased by salinity in rice.

Babu and Thirumurugan (2001) conducted a pot experiment to study the effect of salt priming on growth and development of sesame under induced salinity condition. Salinity was induced by addition of 35, 70 and 140 mM NaCl solution to create three levels of salinity and observed that plant height decreased with the increased salinity level.

Chakraborti and Basu (2001) conducted a pot experiment to study the effect of salinity (0, 6 and 9 dSm^{-1}) on growth and development of sesame under induced salinity condition and observed that number of leaves decreased with the increased salinity level.

El-Midaoui *et al.* (1999) conducted a greenhouse experiment with three sunflower cultivars (cv. Oro 9, Flamme pinto and Ludo) under four salinity levels of 0, 50, 75 and 100 mM NaCl. They reported that plant growth was adversely affected by increasing salinity. Similar results were also reported by Steduto *et al.* (2000) in sunflower.

Shannon and Grieve (1999) reported that salinity changes the roots structure by reducing their length and mass, therefore roots may become thinner or thicker.

Mohammad *et al.* (1998) conducted a pot experiment where tomato seedlings (cv. *riogrande*) were grown in 500 ml glass jars containing Hoagland's solutions which were salinized by four levels of NaCl salt (0, 50, 100 and 150 mM NaCl) and/or enriched with three P levels (0.5, 1 and 2 mM P) making nine combination The results indicate that increasing salinity stress was accompanied by significant reductions in shoot weight, plant height, number of leaves per plant.

Maas (1986) and Bolarin *et al.* (1993) reported that, all stages of plant development including seed germination, vegetative growth and reproduction show sensitivity to salt stress and economic yield is reduced under salt stress.

.**Effect of salinity on Physiological Attributes of plant**

.Eisa (2012) conducted an experiment where *Chenopodium quinoa* plants were grown in a hydroponic quick check system with 0, 100, 200, 300, 400, and 500 mM NaCl (equivalent to 0, 20, 40, 60, 80 and 100% seawater salinity). Higher salinity considerably reduced plant growth, with maximum reduction of 82% observed at 500 mM NaCl. The net photosynthesis rates were greatly decreased by high salinity, being 28% of initial control values at 500 mM NaCl. Salt-induced photosynthesis inhibition was accompanied with a decrease in transpiration rates but also with improved water use efficiency. Salt-induced growth reduction is presumably due to low photosynthate supply as a consequence of impaired photosynthetic capacity.

Haghighi *et al.* (2012) conducted a study to evaluate the effectiveness of salinity on seed germination and growth characteristics of tomato. The experiment was performed with two levels of salinity (25 and 50 mM NaCl) and 2 concentration of Si (1 and 2 mM) with 4 replications. The result showed that seed germination of *Lycopersicon esculentum* L. was significantly affected by salinity levels, Si and their interaction and germination characteristics of tomato decreased drastically increasing by NaCl concentrations. 1 mM Si had positive effects on seed germination characteristics and improved germination percentage, germination rate and mean germination time and Si alleviated the harmful effect of salinity stress on tomato seed germination at almost all germination characteristics.

Akbarimoghaddam *et al*. (2011) evaluated salinity effects on seed germination and seedling growth of six bread wheat cultivars (*Triticum aestivum* L). They reported that water uptake by seeds have a direct relationship with increases in NaCl levels. By increasing NaCl concentration, seed germination delayed and decreased. Increasing NaCl concentrations adversely affected shoot dry weight, shoot dry weight fluctuated by varying NaCl concentration.

Bavei (2011) studied the tolerance of sorghum varieties in terms of fresh weight, ion accumulations, proline content and peroxidase activity was analyzed in this study. Three sorghum varieties, Payam, Kimia, and Jambo, differing in salt tolerance, were grown in a greenhouse-hydroponic culture with a complete nutrition solution to which 0, 50, 100, 150 and 200 mM NaCl was added. Plant roots and leaves were harvested at 15 and 30 days after treatment and subjected to analysis. Clear decline in K^+ and Ca^{2+} concentrations and increase in Na^+ and proline contents were observed in the root and leaf tissues at each NaCl concentration in all varieties during the NaCl treatment.

Hamayun (2010) reported that, the adverse effects of NaCl induced salt stress on growth attributes of soybean and the result showed that Chlorophyll content was significantly decreased in response 70 mM and 140 mM concentrations of NaCl.

Patel *et al.* (2010) reported that, Salinity induced a significant increase in Na^+, Cl^- and proline concentrations, while reduced the accumulation of K^+ and Ca^{2+} in leaves of all the cultivars of cowpea.

Zuccarini (2008) studied the effect of Si on *Phaseolus vulgaris* L. under two level of salinity (30 and 60 mM). His results showed that salinity decreased stomatal conductance and net photosynthetic rate.

Memon *et al.* (2007) experimented on sarokartuho variety of sorghum that was continuously irrigated with fresh (control) and marginally to slightly saline EC 2, 3, 4 and 5 (dSm^{-1}) waters in a pot experiment. Saline water treated plants contained more Na^+, less K^+ and showed lower leaf K^+/Na^+ ratio.

Munns *et al.* (2006) suggested that Na^+ exclusion in plants is attained by low up take of Na^+ by the root cortex, controlled unloading of xylem by parenchyma in the stele. Initial step of transport of Na^+ from soil to plant shoot is entrance of Na^+ into root epidermis and cortex (Na^+ influx.

Numerous studies have revealed that salt stress can reduce K^+, Ca^{2+} and N accumulation in different crop plants, e.g. wheat (Raja *et al. 2006*) sunflower (Akram *et al.*, 2007), radish, cabbage (Jamil *et al.*, 2007) and canola (Ulfat *et al.*, 2007). Salinity reduces nutrient availability as well as transport to the growing regions of the plant, thereby affecting the quality of both vegetative and reproductive organs. For example, higher concentrations of Na^+ in soil decreased the Ca^{2+} activity in the external medium leads to limit its availability in *Celosia argentea* (Carter *et al.*, 2005).

Proline accumulation under stress conditions may be caused by induction of proline biosynthesis enzymes, reduction the rate of proline oxidation conversion to glutamate, decrease utilization of proline in proteins synthesis and enhancing proteins turnover (Claussen, 2005).

A significant decline in the net photosynthesis is an immediate effect of stomatal closure coupled with photorespiration in plants exposed to high salinity stress. This short term response to salinity exposure lasts for 24 - 48 hr and completely ceases photosynthesis (Parida *et al.* 2005).

Ali *et al.* (2004) conducted a research on Salt tolerance in eighteen advanced rice genotypes was studied under an artificially salinized (EC=8.5 dSm^{-1}) soil conditions after 90 days of transplanting. The results showed that the chlorophyll concentration was reduced by salinity.

Azooz *et al.* (2004) studied the salt tolerance of 3 sorghum (*Sorghum bicolor*) cultivars (Dorado, Hagen Shandawil and Giza 113) and their responses to shoot spraying with 25 ppm IAA. The differences in the tolerance of the sorghum cultivars were associated with large differences in K^+ rather than in Na^+, which was found to be similar in the whole plant. The youngest leaf was able to maintain a higher K^+ content than the oldest leaf. Consequently, the K^+/Na^+ ratios were higher in the most salt tolerant cultivar Dorado than in the other sorghum cultivars, and in the youngest than in the oldest leaf. In conformity with this mechanism, the stimulatory effect of the exogenous application of IAA was mostly associated with a higher K^+/Na^+ ratio.

Bhatti *et al.* (2004) subjected 50 wheat lines to stepwise increase in salinity i.e. EC 1.5 (control), 15 and 30 dS m^{-1}. Mineral analysis of cell sap indicated that tolerant lines have minimum Na^+ and Cl^- concentration at EC of 15 dS m^{-1}, whereas, reverse was the case at EC of 30 dS m^{-1}. As the salinity increased, the concentration of Na^+ and Cl^- also increased sharply while Ca^{+2} has opposite trend of variation but K^+ and Mg^{+2} have different behaviors at both the salinity levels in respect to control.

In barley, short term exposure to high salinity leads to an immediate and significant drop in stomatal conductance, due to osmotic stress and local synthesis of ABA (Fricke *et al.,* 2004 and 2006).

Netondo *et al.* (2004) said that, salinity affects photosynthesis mainly through a reduction in leaf area, chlorophyll content and stomatal conductance, and to a lesser extent through a decrease in photosystem II efficiency. Low availability of soil water leads to a transient loss of turgor in plants. It reduces cell elongation, which causes a reduction in leaf expansion, as well as other plant parts, ultimately leading to stunting of the plants.

Netondo *et al.* (2004) conducted an experiment where sorghum plants were grown in sand culture under controlled greenhouse conditions. The NaCl concentrations in complete nutrient solution were 0 (control), 50, 100, 150, 200 and 250 mM. Chlorophyll a and b, net assimilation, stomatal conductance, and transpiration rate decreased significantly with the increase in salinity, and these decreases were similar for the two sorghum varieties.

Parida *et al.* (2004) have reported a significant increase in Na^+ and Cl^- contents in leave, stem and root of mangrove *Bruguiera parviflora* without any significant endogenous alteration of K^+ and Fe^{2+}. Decrease in Ca^{2+} and Mg^{2+} content of leaves has also been reported by salt accumulation in this species.

Soil salinity affects plant growth and development by way of osmotic stress, injurious effects of toxic Na^+ and Cl^- ions and to some extend Cl^- and SO_4^{2-} of Mg^{2+} and nutrient imbalance caused by excess Na^+ and Cl^- ions (Sairam *et al.*, 2004).

High concentration of Na^+ and Cl^- ions in soil solution reduced the uptake of K^+ ions which ultimately caused K^+ deficiency in plants. K^+ deficiency result in chlorosis and then necrosis in plant leaves (Gopal and Dube, 2003).

Lacerda (2003) studied seedlings of two sorghum cultivars, one salt tolerant (CSF 20) and the other salt sensitive (CSF 18) that were grown in nutrient solution containing 0, 50, and 100 m mol $litre^{-1}$NaCl for seven days. The higher decrease in the P seen in the salt-sensitive cultivar was mostly due to higher accumulation of Na^+ and Cl^- that probably exceeded the amount needed for the osmotic adjustment.

Salinity stress is known to result in an excess production of reactive oxygen species (ROS), oxidative damage and a change in concentrations of antioxidants (Bor *et al*., 2003; Sekmen *et al.*, 2007 and Gao *et al.* 2008). Consequently, ROS are good cellular indicators of stress (Mittler, 2002).

Cicek and Cakirlar (2002) observed the effect of salinity on physiological attributes of maize cultivars. They found that salinity caused a marked decrease in relative water contents of maize plants. They further concluded that amount of proline, Na^+ and Na^+/K^+ ratio increased under salt stress condition

Essa (2002) reported that the main response of the plant to salt stress is a change in Ca^{2+} homeostasis and attributed that the salt tolerance of plants is their ability to avoid Na^+ toxicity and to maintain Ca^{2+} and K^+ concentrations.

Munns (2002) reported that salt tolerance of crop to Na^+ is due to Na^+ exclusion from the shoot. In wheat, salt tolerance is owing to Na^+ exclusion from leaves (Husain *et al.*, 2003).

Thimmaiah (2002) carried out an experiment where sorghum (*Sorghum bicolor*) was grown under different levels of salinity (1, 2, 4, 6, 8 and 12 dSm^{-1}) in irrigation water and investigated for yield and yield components and biochemical composition. K^+ and Ca^{2+} content, protein content and total amylolytic enzyme activity differed significantly due to salinity. However, these parameters were, more or less, at par with each other in the range of 2 to 8 dSm^{-1}. Among the chemical constituents, increased salinity levels increased Ca^{2+} content and decreased K^+ content.

Plant stresses, including salinity stress, are known to disturb cellular homeostasis, enhancing the production of ROS (Dat *et al.* 2000). Additionally, osmotic stress, one of the foremost stresses associated with high salinity levels, has shown to cause the production of ROS (Xiong and Zhu, 2002).

Silberbush (2001) studied that Potassium (K^+) uptake by plant roots is often suppressed by sodium (Na) in the growth medium, whose damage may be moderated by calcium (Ca^{2+}). There is a debate if K^+ influx could be used as an index to salinity tolerance and the reliability of its determination by the ion depletion method. Two sorghum (*Sorghum bicolor*) varieties (Hegari and NB- 9040), that differ in their salt tolerance grew for 28 days in nutrient solutions with 0, 25, 50 and 75 mm NaCl. In addition, the effect of Ca was determined in the presence of 2 and 5 mM Ca^{2+} with plants grown in 50 mM NaCl.

Tomato and alfalfa leaves showed a significant reduction in total chlorophyll content, when exposed to salinity levels of 100 mM of NaCl (Khavari and Mostofi, 1998).

Hu *et al.* (1997) showed that salinity significantly increased sodium and chloride concentration in leaves and stems of wheat, while the concentration of K^+, Ca^{2+}, Mg^{2+} and NO_3^- decreased. Both K^+ and Ca^{2+} are required in the external growth medium to maintain the selectivity and integrity of the cell membrane

Iyengar and Reddy (1996) explained several factors contributing to decline in photosynthetic rate. A physiological water deficit and a reduction in water potential lower the photosynthetic efficiency of plants under salinity stress, thus lowering the net carbon assimilation rate.

Reddy *et al.* (1992) reported a significant reduction in stomata conductance and CO_2 assimilation rate in salt stressed *Salicornia brachiata* Plants which prevented optimal activities of several enzymes in Calvin cycle. Similarly, salt stress aggravated photo-inhibition and delayed recovery of photosynthetic apparatus in wheat cultivars (Mishra *et al.*, 1991).

According to Greenway and Munns (1986), the reduction in K^+ concentration could inhibit growth by reducing the capacity for osmotic adjustment and turgor maintenance or by adversely affecting metabolic functions.

Effect of salinity on yield and yield contributing characters of plant:

An experiment was conducted by Saberi *et al.* (2011). She found that increased salinity significantly reduced forage dry yield from 44.09 gm plant^{-1} in the control to 32.76 g plant^{-1} at salinity with 15 dSm^{-1}. For every one unit increase in salinity, the forage yield decreased by 5.2 units and for every one unit increase in water stress (irrigation frequency), the forage yield decreased by 3.6 units.

Hamayun *et al.* (2010) reported that, the adverse effects of NaCl induced salt stress on growth attributes and endogenous levels of gibberellins (GA), abscisic acid (ABA), jasmonic acid (JA) and salicylic acid (SA) soybean cv. Hwangkeumkong was showed. 1000 seed weight and yield significantly decreased in response 70 mM and 140 mM concentrations of NaCl.

Prakash and Chen (2010) observed that all the physiological properties and yield were negatively affected by increasing salinity levels due to less water use and radiation interception. Compared to the low salinity level, medium and high salinity levels reduced the above-ground dry weight of the crop at harvest by 40 and 41%, accumulated intercepted radiation by 23 and 37%, radiation use efficiency by 25 and 52%, water use by 18 and 35% and grain yield by 41 and 48%, respectively.

Rafat and Rafiq (2009) reported that, total chlorophyll content in tomato plant proportionally decreased with the increase in salinity levels up to 0.4% sea salt solution (EC 5.4 dSm^{-1}).

Karim (2007) conducted an experiment to investigate the effect of different salinity levels (0, 6, 9 and 12 dSm^{-1}) and reported that all parameters including panicle length decreased with increased salinity levels. Panicle length was adversely affected by soil salinity levels as reported by most of the researchers (Islam *et al.,* 1998; Hossain, 2002; Islam, 2004; Natarajan *et al.,* 2005 and Rana, 2007).

Karim (2007) reported that grain yield decreased with increased salinity levels. The yield was decreased due to production of decreased number of effective tillers hill^{-1}, decreased number of grains panicle^{-1}and 1000-seed weight. Similar result was also reported by many researchers (Islam *et al.,* 1998. Hossain, 2002; Sen, 2002; Islam 2004; Rashid, 2005 and Hossain, 2006).

Rana (2007) carried out a pot experiment with 5 levels of salinity (0, 3, 6, 9 and 12 dS/m) of three rice varieties viz., BRRl dhan-42, STM-1 and STM-2 and reported that plant height, number of tillers hill^{-1}, TDM hill^{-1}, leaf area hill^{-1}, root dry weight hill^{-1} and yield contributing characters and yield decreased significantly with increase in salinity levels. Among the advanced rice lines BRRIdhan-42 showed more tolerance for all studied parameters compared to STM-1 and STM- 2.

Amini and Ehsanpour (2006) reported decrease in chlorophyll content in tomato cultivar due to salt stress.

Hajer *et al.* (2006) and Cuartero and Munoz (1999) conducted two different experiment separately on tomato under saline condition and reported the effect of NaCl salinity stress on the growth of tomato plants was reflected in lower fresh and as well as dry weights.

Ali *et al.* (2005) conducted a pot experiment with three salinity levels (0, 6 and 9 dSm^{-1}) and observed that 1000-seed weight decreased with increased salinity level in sesame. Again, Thakral *et al.* (1996) studied six *B. carinatus* species under 0-125 meq L^{-1} chloride solution and observed that siliqua plant^{-1}, 1000-seed weight and seed yield decreased under salinity.

El-Hendawy *et al.* (2005) reported that tiller number of wheat was affected more by salinity than leaf number and leaf area at the vegetative stage. Salinity decreased dry weight per plant significantly at all growth stages. Spikelet number on the main stem decreased much more with salinity than spike length, grain number and 1000-grain weight at maturity. They also concluded that an increase in tiller number per plant and spikelet number per spike will improve the salt tolerance of wheat genotypes in breeding programs.

Uddin *et al.* (2005) conducted an experiment to study salt tolerance of *B. napus* and *B. campestris* varieties under saline conditions (1.2-11.5 dSm^{-1}) and observed that siliqua number and seeds siliqua^{-1} decreased with increased salinity.

Gain *et al.* (2004) studied the effect of salinity (0, 7.81, 15.62, 23.43 and 31.25 dSm^{-1}) on yield attributes and yield in rice and reported that number of spikelet panicle^{-1}, 1000-grain weight and dry mass decreased with increasing salinity levels but the decrement was less in salt tolerant varieties than salt susceptible varieties This statement was supported many workers (Ahmed *et al.*, 1980; Islam *et al.*, 1998; Islam, 2004 and Hossain, 2006).

Netondo *et al.* (2004) conducted an experiment to determine how salinity affects growth, water relations, and accumulation of cations of nutritional importance in various organs of grain sorghum. Two Kenyan sorghum varieties, Serena and Seredo, were grown in a greenhouse in quartz sand supplied with a complete nutrient solution to which 0 (control), 50, 100, 150, 200, and 250 mM NaCl was added. The 250 mM NaCl treatment significantly reduced the relative shoot growth rates, measured 25 days after the start of salt application, by 75 and 73%, respectively, for Serena and Seredo, and stem dry weight by 75 and 53%.

A field experiment was conducted by Leena (2003) in Vadodara, Gujarat, India to test the effect of salt stress on *Sorghum bicolor*. Though there was a reduction in the chlorophyll content of the plants subjected to salt stress, the fresh and dry weights of the plants were reduced only at the earlier stages.

Debnath (2003) and Rahman (2003) worked with mustard to know the effect of different levels of salinity (0, 5, 7, 10 and 15 dSm^{-1}) on yield attributes and dry matter partitioning and reported that harvest index decreased with increased salinity levels.

Hossain (2002) conducted a pot experiment with three salinity levels (0, 6 and 9 dSm^{-1}) and observed that harvest index decreased with increase of salinity level in rice. Similarly, Islam (2004) reported that harvest index decreased with the increase of salinity level in rice. Again, Hossain (2006) worked with rice to know the effect of different levels of salinity (0, 6, 9, and 15 dSm^{-1}) on yield attributes and dry matter partitioning and reported that harvest index decreased with increased salinity levels. Similar result was also reported by Rana (2007) in rice.

Parti *et al*. (2002) conducted an experiment where salinity levels of 4, 8 and 12 dSm^{-1} were obtained from adding chloride and sulphate salts of sodium, calcium and magnesium. All salinity treatments affected plant growth considerably. The dry matter weight was maximum at 4 dSm^{-1} and beyond this level, a constant decreased with increased salinity in TDM, plant height and siliqua $plant^{-1}$ was observed.

Sen (2002) conducted a pot experiment with three salinity levels (3, 6 and 9 dSm-1) and observed that 1000- grain weight decreased with increased salinity level in rice. Similar result was also reported by Abudullah *et al.* (2001) in rice.

Thimmaiah (2002) grew sorghum (*Sorghum bicolor*) under different levels of salinity (1, 2, 4, 6, 8 and 12 dSm^{-1}) in irrigation water and investigated for yield and yield components and biochemical composition. Seed and straw yield, seed weight per ear, N, P, K and Ca content, protein content and total amylolytic enzyme activity differed significantly due to salinity. However, these parameters were, more or less, at par with each other in the range of 2 to 8 dSm^{-1}. The 1000-seed weight, Mg^{2+} content and invertase [beta-fructofuranosidase] enzyme 14 activity were unaffected by salinity. Except 1000-seed weight, yield and yield components decreased significantly at 12 dSm^{-1} salinity.

Abdullah *et al.* (2001) conducted an experiment for finding out the effect salinity stress on seed set of IR-28 rice under different salinity levels and found that panicle length was significantly decreased due to salinity stress.

Chakraborti and Basu (2001) studied salt tolerance ability in 9 sesame varieties under saline condition and reported that capsule per plant, seeds per capsule and seed yield decreased under saline condition in all studied varieties of sesame.

Sultana *et al.* (1999) evaluated the effect of salinity on rice at reproductive stage and observed that low concentration of assimilate in the leaves and poor translocation of assimilates from source to sink resulted less number of filled grain set while reverse trend was observed in unfilled grain number $panicle^{-1}$.

Khavari and Mostofi (1998) reported that chlorophyll content was reduced with higher salinity levels at all growth stage where the reduction rate was greater at vegetative growth stage than maturity stage in tomato.

Admans and Ho (1989) and Vanleperen (1996) conducted three different experiments at different time to find out the effect of salinity on tomato and they reported separately that, the number of cluster $plant^{-1}$ was reduced both with high salinity and long salinization periods in case of tomato. Whereas Mubarak (2011) also observed the fruit size reduced with salinity over control.

Belda and Ho (1993) conducted an experiment on tomato and reported that salinity reduced the xylem development in tomato fruit but since the tomato fruit has a very low transpiration rate, only a small proportion of the water input come via the xylem (Ho *et al.* 1987) thus reduced the individual fruit size as well as weight.

Gonzalez- Fernandez and Cuartero (1993) reported that a 10% reduction in fruit weight is caused following irrigation with 5-6 dSm^{-1} water, a 30% reduction with 8dSm^{-1} and about 40% at higher EC.

Grunberg *et al.* (1993) reported that fruit set could be decreased because of low number of pollen grains $flower^{-1}$ in plant under salt stress, extra flower production would be inhibited (Saito and Ito, 1974).

Jonson *et al.* (1992) reported that individual fruit weight decreased with increased salinity due to the reason of high salinity lowering the water potential in the plant which will reduce the water flow into the fruit and therefore the rate of fruit expansion.

Brungnoli and Lauteri (1991), Alberioco and Cramer (1993) reported that growth of leaf area is inhibited by salinity.

Cuartero and Munoz (1990) observed salinity adversely affected the fruits number $plant^{-1}$ of tomato under different levels of salinity. The number of fruits $plant^{-1}$ was gradually reduced with increased levels of salt.

Nasiruddin and Rahman (1980) found that the reduction of yield in aman rice by 13% was due to use of salt concentration of 4 to 8 m mhos/cm. They also reported that the yield reduction was 62%, caused by the application of salt concentration of >15 m mhos cm^{-1} in Khulna area of Bangladesh.

From the above review of literature, it may be concluded that salinity has marked effect on plant growth and development as well as yield of crops.

Effect of salicylic acid on plant growth and development under salinity stress

Salicylic acid (SA) is a phenolic compound involved in the regulation of growth and development of plants, and their responses to biotic and abiotic stress factors. (Raskin, 1992; Khan *et al*., 2012a, b, c, 2013b; Miura and Tada, 2014).

SA is involved in the regulation of important plant physiological processes such as photosynthesis, nitrogen metabolism, proline (Pro) metabolism, production of glycinebetaine (GB), antioxidant defense system, and plant-water relations under stress conditions and thereby provides protection in plants against abiotic stresses 01(Khan *et al*., 2010, 2012a,b,c, 2013b, 2014; Nazar *et al*., 2011; Miura and Tada, 2014). Apart from its involvement in the induction of defense-related genes and stress resistance in biotic stressed plants (Kumar, 2014), SA has been shown to improve plant tolerance to major abiotic stresses such as metal (Zhang *et al*., 2015), salinity (Khan *et al*., 2014; Nazar *et al*., 2015), osmotic (Alavi *et al*., 2014), drought (Fayez and Bazaid, 2014), and heat stress (Khan *et al*., 2013b).

Exogenously sourced SA to stressed plants, either through seed soaking, adding to the nutrient solution, irrigating, or spraying was reported to induce major abiotic stress tolerance-mechanisms (Horváth *et al*., 2007; Khan *et al*., 2012a,b,c, 2013b, 2014; Anwar *et al*., 2013 and Palma *et al*., 2013). SA influences plant functions in a dose dependent manner, where induced or inhibited plant functions can be possible with low and high SA concentrations, respectively. For example, in *Matricaria chamomilla*, 50 and 250 μM SA concentrations were reported to, respectively, promote and inhibit growth (Kováčik *et al*., 2009). In another instance, 0.1 and 0.5 mM SA promoted photosynthesis and growth of *Vigna radiata* but an inhibited growth was evidenced with 1.0 mM SA (Nazar *et al*., 2011). Besides the concentration of SA, the duration of the treatment, plant species, age, and treated plant organ can also influence the SA-effects in plants (Shi *et al*., 2009; Miura and Tada, 2014).

Salicylic acid could be used as a potential growth regulator for improving growth and development under abiotic stresses (Singh and Usha, 2003). Various researchers reported increase in yield due to spray of SA on maize (DeGuang *et al*., 2001), Shakirova *et al*., 2003), soybean (Kumar *et al*., 2000), mungbean (Singh and Kaur, 1980).

The role of SA in strengthening salinity stress-tolerance mechanisms has been extensively evidenced in many crops including *Vicia faba* (Azooz, 2009), *Brassica juncea* (Nazar *et al*., 2011, 2015), *Medicago sativa* (Palma *et al*., 2013), and *V. radiata* (Khan *et al*., 2014).

Salicylic acid was reported to induce salinity tolerance and increased biomass of *Torreya grandis* as a result of enhanced chlorophyll content and the activity of antioxidant enzymes that eventually activated the photosynthetic process and alleviated oxidative stress (Li *et al.*, 2014).

Sumaira *et al*. (2014) conducted an experiment to alleviate the salinity-induced harmful effect on biomass production and physiochemical attributes of fenugreek by foliar application of salicylic acid. Two varieties (Deli Kabul and Kasuri) were grown in salt treated (100 mM NaCl) and untreated (0 mM NaCl) growth medium. Results showed that higher shoot fresh weight was recorded in Deli Kabul, while lower in Kasuri. Such reduction in growth biomass was mitigated by the foliar application of SA in both plants. Salinity caused net CO_2 assimilation rate, transpiration rate, stomatal conductance, and substomatal CO_2 concentration. Exogenous applied salicylic acid also overcomes the reduction in gas exchange attributes of the plants. The varieties "Deli Kabul" and "Kasuri" showed higher and lower net CO_2 assimilation rate, respectively. These results indicate that growth medium salinity induced reduction in biomass production, gas exchange attributes, and also chlorophyll contents whereas the application of SA through foliar method can be used to protect plant growth and improve these attributes under salt stress.

Enrique *et al*. (2010) conducted an experiment to determine the SA concentration in leaves, the change in catalase (CAT) activity and the change in total antioxidant capacity (TAC) that result from the exogenous application of SA (10-4 M) to tomato leaves every 15 days in a greenhouse with and without NaCl application. He observed that the spray application of SA in the absence of NaCl significantly increased the concentration of SA (up to 145 and 289% for the first and second application respectively) and CAT activity (up to 182% for the third application) in leaves, without affecting fruit yield. The application of SA in combination with 100 mM NaCl had the highest values of SA (up to 381 and 258% for the second and third application respectively) and CAT activity (up to 142 and 294% for the first and third application respectively), without changing consistently the TAC of the leaves and without any effect on fruit production. The application of 100 mM NaCl did not affects the CAT activity, TAC or SA into the leaves, or fruit production.

An experiment was conducted by Mohsina (2008) to study the effect of salicylic acid seed priming on growth and some biochemical attributes in wheat (*Triticum aestivum* L.) grown under saline conditions. Wheat seeds of cv. Inqlab and S-24 were soaked in water and 100 mg L^{-1} salicylic acid solution for 24 hours and sown in sand salinized with 0, 50 or 100 mM NaCl. Salt stress significantly reduced all growth parameters (shoot and root length, and shoot and root dry weights) and salicylic acid treatment alleviated the adverse effect of salinity on growth. Salinity decreased the chlorophyll a and b content and chlorophyll a/b ratio in both the lines, but reduction in chlorophyll a/b ratio was lower in salt tolerant wheat line S-24, which could be a useful marker for selection of salt tolerant wheat.

Sibgha *et al.* (2008) conducted an experiment to assess whether exogenously applied SA as a foliar spray could ameliorate the adverse effects of salt stress on sunflower plants. Two lines of sunflower (Hisun-33 and SF-187) were grown under normal or saline (120 mM NaCl) conditions. Different levels of salicylic acid (0, 100, 200, 300 mg L^{-1}) were applied as a foliar spray. Salt stress reduced the growth of both lines, but both cultivars were equally responsive to the stress and application of 200 mg L^{-1} of SA caused an increase in biomass and photosynthetic rate of both cultivars under control and saline conditions, particularly in line SF-187.

Ali *et al*. (2007) have reported an increase in anti-oxidative potential in *Panax ginsenge* roots by the application of 200 μM SA.

El-Tayeb, (2005) reported that SA application increased peroxidase contents, membrane permeability and lipid peroxidation in barley grains under salt stress.

El-Tayeb (2005) reported that foliar application of 1.0 mM SA increased RWC, fresh and dry weights, water content, soluble protein, total free amino acids, proline content, photosynthetic pigments, and phosphorus and peroxidase activity of barley seedlings under varying salt treatments.

Shakirova *et al*. (2003) reported that application of 0.05 mM SA through growth medium with 2% sucrose under NaCl stress reduced the damaging effects on growth of wheat seedlings. It caused increase in ABA and IAA levels in plant tissue and the high level of ABA and proline induced anti-stress reaction.

Moharekar *et al*. (2003) reported that foliar application of various levels of SA (0, 5, 10, 50, 100 mg kg-1) increased carotenoid content and size of xanthophyll pool.

Salicylic acid induced resistance against salinity stress in wheat (Shakirova *et al*., 2003), rice and cucumber seedlings (Shim *et al*., 2003), increased growth of shoots and roots of soybean (Coronado *et al*., 1998), maize (Khodary, 2004) and barley seedlings (El-Tayeb, 2005) under salt stress.

Kalarani *et al*. (2002) reported that foliar application of SA (0, 50, 100, 200 mg L^{-1}) induced early flowering in mango trees by 6 to 10 days and enhanced fruit set from 22 to 32%.

Tari *et al*. (2002) observed that tomato plants tolerated 100 mM NaCl at low levels of SA concentration (10-7 to 10-4 M range) by a substantial increase in photosynthetic rate, transpiration rate and stomatal conductance.

The application of 2000 mg L-1 SA resulted in the highest fruit yield of mango (48.7 kg tree-1), photosynthetic rate (8.2 µmol m^{-2} s^{-1}) and stomatal resistance (0.456 s cm^{-1}), with concurrent reduction in malformed panicles by 30% (Singh *et al*., 2001).

The role of SA in defence mechanism shows promise in alleviating the adverse effects of salt stress on plants (Al-Hakimi and Hamada, 2001 and Gunes *et al*., 2007).

The harmful effects of oxidative stress may not be ameliorated by indigenous antioxidant system under stressful conditions (Ding *et al*., 2002). SA induces antioxidant defense by stimulating many antioxidant enzymes, which are necessary for plant protection against osmotic and salt stress as well as other stresses (Erdei *et al*., 1996). The application of 500 µM SA on barley plants improved antioxidant system (Popova *et al*., 2003).

Coronado *et al.* (1998) a reported a significant increase in biomass of shoots and roots of soybean by SA application. Foliar application of SA also increased stomatal conductance or resistance and reduced the transpiration in pepper seedlings (Eris, 1983). Significant increase in water-use-efficiency (WUE) and carboxylation efficiency occurred due to foliar spray of SA (Kumar *et al*., 2000).

Afzal *et al*. (2006) recorded an increase in wheat seed germination and seedling vigour by priming of seed with 50 mg kg^{-1} SA under saline conditions (15 dSm^{-1}). Similarly, Stevens and Senaratna (2006) reported a 4-fold increase in growth rate, higher photosynthetic and transpiration rates than those in untreated check by drenching tomato roots with 0.1 mM SA under 200 mM NaCl conditions. SA increased the number of flowers, pods/plant and seed yield of soybean (Gutierrez-Coronado *et al*., 1998), and enhanced growth of wheat (Shakirova *et al*., 2003) and maize (Abdel-Wahed *et al*., 2006; El-Mergawi and AbdelWahed, 2007). Electrolytic leakage from plant tissues is one of the most prominent effects of the salinity on plants. However, application of SA reduced electrolyte leakage in tomato (Stevens and Senaratna, 2006) in seedlings of wheat (Afzal *et al*., 2006) and barley (El-Tayeb, 2005) under salt stress.

It is obvious that lower concentration of SA enhanced the stress tolerance by altering morphophysiology to salt stress in many crops including wheat.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted during the period from November 2014 to March 2015. The materials and methods those were used and methods followed for conducting the experiment have been presented under the following headings.

3.1 Experimental site

This study was conducted in the research field of Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh. The location of the experimental site is 23°74′N latitude and 90°35′E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004).

3.2 Characteristics of soil

The soil of the experimental area belongs to the Modhupur Tract (Anon., 1988) under AEZ No. 28. The characteristics of the soil under the experiment were analyzed in the Laboratory of Soil science Department, SAU, Dhaka and details of soil characteristics have been presented in Appendix I.

3.3 Climatic condition of the experimental site

The experimental site is situated in the subtropical monsoon climatic zone, which is characterized by heavy rainfall during the months from April to September (Kharif season) and scanty of rainfall during rest of the year (Rabi season). Plenty of sunshine and moderately low temperature prevail during October to March (Rabi season), which are suitable for growing of wheat in Bangladesh.

3.4 Planting materials

The variety BARI Gom-25 was used. The seeds of wheat were grown at the research field in Sher-e-Bangla Agricultural University. BARI Gom-25, a high yielding salt tolerant variety of wheat was developed by the Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur, Bangladesh. It was released in 2010. Its total duration is about 102-110 days after sowing.

3.5 Treatments of the experiment

The two factorial experiments will be carried out in Randomized Complete Block Design (RCBD) with four replications having

Factor (A) Different levels of salinity (NaCl):

i. S_0 = without salt (control)
ii. S_1 = 2.8 g NaCl kg^{-1} of soil ≈ 3-4 dSm^{-1}
iii. S_2 =6.0 g NaCl kg^{-1} of soil ≈ 7-8 dSm^{-1}
iv. S_3 = 9.0 g NaCl kg^{-1} of soil ≈ 11-12 dSm^{-1}

Factor (B) Different concentrations of Salicylic acid (SA):

i. A_0 = 0 mM SA
ii. A_1 = 0.2 mM SA
iii. A_2 = 0.4 mM SA

Total 12 treatment combinations were as follows:

S_0A_0: Without Salt+ Without Salicylic Acid

S_0A_1: Without Salt +0.2 mM Salicylic Acid

S_0A_2: Without Salt + 0.4 mM Salicylic Acid

S_1A_0: 2.8 g NaCl kg^{-1} soil + Without Salicylic Acid

S_1A_1: 2.8 g NaCl kg^{-1} soil + 0.2 mM Salicylic Acid

S_1A_2: 2.8 g NaCl kg^{-1} soil + 0.4 mM Salicylic Acid

S_2A_0: 6.0 g NaCl kg^{-1} soil + Without Salicylic Acid

S_2A_1: 6.0 g NaCl kg^{-1} soil + 0.2 mM Salicylic Acid

S_2A_2: 6.0 g NaCl kg^{-1} soil + 0.4 mM Salicylic Acid

S_3A_0: 9.0 g NaCl kg^{-1} soil + Without Salicylic Acid

S_3A_1: 9.0 g NaCl kg^{-1} soil + 0.2 mM Salicylic Acid

S_3A_2: 9.0 g NaCl kg^{-1} soil + 0.4 mM Salicylic Acid

3.6 Design and layout of the experiment

The two factors experiment was laid out in Randomized Complete Block Design (RCBD) with four levels of salinity and three levels of salicylic acid. Four replications were maintained in this experiment. The total number of unit pots was 48 (12×4). Each pot was 35 cm (14 inches) in diameter and 30 cm (12 inches) in height. The experiment was placed under the net house which was made by bamboo with net and pots were kept on the individual earthen plate.

3.7 Application of the treatments and pot preparation

Wheat plants were treated with 0, 2.8, 6.0 and 9.0 g of sodium chloride (NaCl) per kg soil to attain the level of salinity 0, 3-4, 7-8 and 11-12 dSm^{-1} respectively. Salt was applied in two ways. According to treatment half of the total amounts of salts were mixed in soil and were covered with polythene sheet for three (3) days. Then the treated soil was put into the pot which contains 10 kg soil per pot. For undisturbed germination normal soil was spread on the pot in a layer of 2 cm. All 48 pots were filled on 30th November 2014. Weeds and stubbles were completely removed from the soil. Again, rest half amounts of the salt were applied through irrigation water after germination of seed. As a salt stress mitigation agent, salicylic acid (SA) was sprayed exogenously at 0, 0.2 mM and 0.4 mM concentrations which were maintained by adding 0, 0.03 g and 0.06 g SA respectively per liter of water and 0.1% of Tween-20 was used as an adhesive material. At 30 and 50 DAS the SA solution was sprayed by a hand sprayer at 10 am. The SA used in the form of C_6H_4 (OH) COOH of Merck India and salt in the form of NaCl which collected from local market.

3.8 Seed sowing

Seeds were sown on 30th November, 2014. Twelve (12) seeds were sown in each pot. Seeds were placed in 1 cm depth, and then covered with soil properly.

3.9 Intercultural operations

3.9.1 Irrigation

Light watering was provided with water cane immediately after sowing of seeds and this technique of irrigation was used as required. The amount of irrigation water was limited up to that quantity which does not leached out through the bottom. The water was deposited on the earthen plate which was further poured into the pot again for maintaining the salinity level as treatment.

3.9.2 Thinning

Thinning was done as required and finally eight plants kept in each pot. Four to five plants are kept at higher level of salinity because salinity affects the rate of germination differently.

3.9.3 Weeding

Weeding was done whenever it was necessary, mostly in vegetative stage.

3.9.4 Plant Protection Measures

Melathion 57 EC was applied @ 2 ml L^{-1} of water against the cutworm when needed.

3.10 Harvesting

Maturity of crop was determined when 90% of the spike became golden yellow in color. Three plants per pot were preselected randomly from which different growth and yield attributes data were collected and then each pot was harvested separately and bundled, properly tagged and then brought to the threshing floor for recording grain and straw yield. The grains were cleaned and sun dried to a moisture content of 12%. Straw was also sun dried properly.

3.11 Recording of Data

Experimental data were recorded from 45 days of sowing and continued up to harvest. The following data were recorded during the experimentation.

A. Morphological characters

1. Plant height (cm)
2. Number of leaves plant^{-1}
3. Number of tillers hill^{-1}
4. Number of effective tillers hill^{-1}

B. Physiological characters

5. Fresh weight plant^{-1} (g)
6. Dry weight plant^{-1} (g)
7. SPAD value
8. Membrane stability (%)

C. Yield contributing and yield characters

9. Number of grains spike^{-1}
10. Number of spikelet spike^{-1}
11. Grain weight spike^{-1} (g)
12. 1000 grain weight (g)
13. Grain yield (t ha^{-1})
14. Straw yield (t ha^{-1})
15. Biological yield (t ha^{-1})
16. Harvest Index (%)
17. Mitigation (%)

3.12 Detailed Procedures of Recording Data

A brief outline of the data recording procedure followed during the study is given below:

A. Morphological characters

1. Plant height (cm)

Plant height was measured at 45, 60 days after sowing (DAS) and at harvest. The height of the plant was determined by measuring the distance from the soil surface to the tip of the leaf. The collected data were finally averaged.

2. Number of leaves plant^{-1}

Leaf number was counted at 60 DAS. The number of leaves plant^{-1} was counted three plants of each pot and then averaged.

3. Number of tillers hill^{-1}

Number of tillers hill^{-1}were counted at 60 DAS from three plants of each pot and then averaged.

4. Number of effective tillers hill^{-1}

Number of effective tillers hill^{-1}were counted at 60 DAS from three plants of each pot and then averaged.

5. Fresh weight plant^{-1} (g)

Three plants at 60 days after sowing (60 DAS) were collected and cleaned then weighed and averaged.

6. Dry weight plant^{-1} (g)

Three plants at 60 days after sowing (60 DAS) were collected and oven dried at 70°C for 72 hours. The dried samples were then weighed and averaged.

B. Physiological characters

7. SPAD value

Leaf chlorophyll content was analyzed as measured in SPAD value using a hand-held SPAD meter (CCM-200, Opti-Science, USA). At each evaluation the value was measure 3 times from three leaves at different positions plant^{-1} and the average was used for analysis.

8. Membrane stability (%)

The plasma membrane intactness was estimated through the leakage of electrolytes, described by Sun et al. (2006). Fresh leaves (0.30 g) were placed in tubes, containing 30 ml distilled water and kept for 2 h in water bath at 30 °C for measuring the initial conductivity (EC1). The final electrolyte conductivity (EC2) was measured after boiling the plant samples for 15 min. The leakage percentage was calculated as (EC1/EC2) x100 %.

C. Yield contributing and yield characters

9. Number of grains spike^{-1}

The number of grains spike^{-1} was counted from 3 spikes and number of grains spike^{-1} was measured by the following formula-

$$\text{Number of grains spike}^{-1} = \frac{\text{Total number of filled(fertile) spikelets of the sample spikes}}{\text{Number of sample spikes}}$$

10. Number of spikelet spike^{-1} (g)

Total number of spikelet in a spike was counted. It included both sterile and non-sterile spikelets.

11. Grain weight spike^{-1} (g)

Grains were collected from each individual spike and then weighed and recorded which was expressed in grams.

12. 1000 grain weight (g)

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

13. Grain yield (t ha^{-1})

Grain yield hectare^{-1} of wheat was calculated by converting the weight of grain yield into hectare on the basis of ton hectare^{-1}.

14. Straw yield (t ha^{-1})

Straw yield hectare^{-1} of wheat was calculated by converting the weight of straw yield into hectare on the basis of ton hectare^{-1}.

15. Biological yield (t ha^{-1})

Biological yield of a crop is defined as the sum of grain yield and straw yield. The biological yield of wheat was measured for each plot and express in gram per pot.

The biological yield was estimated with the following formula:

Biological yield = Grain yield + Straw yield

16. Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with the following formula (Gardner *et al*., 1985).

$$\text{HI (\%)} = \frac{\text{Economic yield (Grain weight)}}{\text{Biological yield (Grain yield + Straw yield)}} \times 100$$

17. Mitigation (%)

Mitigation percent was measured by the following formula:

$$\text{Mitigation (\%)} = \frac{\text{Yield value of treatment combination}}{\text{Yield value of control treatment}} \times 100$$

3.13 Statistical Analysis

All the data collected on different parameters were statistically analyzed following the analysis of variance (ANOVA) technique using MSTAT-C computer package program and the mean differences were adjudged by least significant difference (LSD) test at 5% level of significance (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DICUSSION

The results obtained with different levels of salinity (S) and salicylic acid (SA) and their combinations are presented and discussed in this chapter. Data about morpho-physiological parameters, yield contributing characters and grain yield of wheat have been presented in both Tables and Figures and analyzes of variance and corresponding degrees of freedom have been shown in Appendices.

4.1 Plant height

4.1.1 Effect of salinity

The plant height (cm) varied significantly due to the effect of salinity stresses observed at 45, 60 days after sowing (DAS) and at harvest with statistically significant variation (Table 1 and Appendix III). At 45, 60 DAS and at harvest, the highest plant height 66.73 cm, 73.57 cm and 77.08 cm, respectively was found from S_0 or control whereas the lowest value 57.74 cm, 61.49 cm and 64.89 cm, respectively was observed with S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The results of this study showed that salinity significantly reduced the plant height of wheat at different DAS and the reduction was quite incremental with the increase of NaCl concentrations. Salinity generally provides a slow growth and development of cells which is confirmed by Munns (2002) who reported salinity reduces plant growth through lessening or stopping the leaf expansion. This factor suppresses the turgor pressure and metabolic activities in the cells that are observed as low number and small size of leaves associated with short plant height. Memon *et al.* (2007) stated that increasing water salinity progressively decreased plant height and fodder yield (fresh and dry weight) per plant.

Table 1. Effect of different levels of salinity on plant height at different days after sowing (DAS) of wheat

Treatment	Plant height (cm)		
	45 DAS	60 DAS	At harvest
S_0	66.73 a	73.57 a	77.08 a
S_1	65.88 b	72.87 b	76.34 b
S_2	62.90 c	69.87 c	73.35 c
S_3	57.74 d	61.49 d	64.89 d
$LSD_{(0.05)}$	0.596	0.315	0.365
Significant level	**	*	*
CV (%)	5.61	4.74	4.81

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
** significant at 1% level of probability, * significant at 5% level of probability

4.1.2 Effect of salicylic acid

Salicylic acid had significant effect on plant height of wheat at 45, 60 DAS and at harvest (Table 2 and Appendix III). At 45, 60 DAS and at harvest, the tallest plant height 64.94 cm, 71.23 cm and 74.71 cm, respectively was recorded from A_2 or 0.4 mM salicylic acid (SA) whereas the shortest 61.50 cm, 67.64 cm and 71.10 cm, respectively was observed with A_0 or control. This result agreed with Qados (2015) who reported that SA treatment improved the plant height at all levels of salt stress and also control plants, it is therefore acting as growth stimulants. It seems that SA treatment could completely counteract the negative effect of low (4000 ppm) and medium (2000 ppm) salt stress and partially counteract the harmful effect of medium and high (6000 ppm) salt stress.

Table 2. Effect of different concentration of salicylic acid on plant height at different days after sowing (DAS) of wheat

Treatment	Plant height (cm)		
	45 DAS	60 DAS	At harvest
A_0	61.50 c	67.64 c	71.10 c
A_1	63.49 b	69.49 b	72.92 b
A_2	64.94 a	71.23 a	74.71 a
$LSD_{(0.05)}$	0.516	0.273	0.316
Significant level	**	**	**
CV (%)	4.61	4.74	4.81

A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability

4.1.3 Interaction effect of salinity and salicylic acid

Interaction of salinity and salicylic acid showed significant variation on plant height of wheat at 45, 60 DAS and harvest (Table 3 and Appendix III). At 45, 60 DAS and harvest, the highest plant height 68.64 cm, 75.89 cm and 79.41cm, respectively was observed from the S_1A_2 treatment which was statistically similar with S_0A_2 (68.43 cm, 75.51 cm and 79.08 cm) and the lowest 56.58 cm. 60.56 cm and 64.00 cm, respectively plant height was observed from S_3A_0 treatment combination. The positive effect of foliar application with SA on the growth parameters and water status has also been reported under stress conditions (Khodary, 2004; Hussein *et al.,* 2007; Erdal *et al.*, 2011).

Table 3. Interaction effect of different levels of salinity and salicylic acid on plant height at different days after sowing (DAS) of wheat

Treatment	Plant height (cm)		
	45 DAS	60 DAS	At harvest
S_0A_0	65.03 cd	71.74 d	75.16 d
S_0A_1	66.74 b	73.46 b	76.99 b
S_0A_2	68.43 a	75.51 a	79.08 a
S_1A_0	63.00 f	69.86 f	73.31 f
S_1A_1	65.99 bc	72.88 c	76.31 c
S_1A_2	68.64 a	75.89 a	79.41 a
S_2A_0	61.41 g	68.39 g	71.94 g
S_2A_1	63.22 ef	70.14 f	73.58 f
S_2A_2	64.07 de	71.08 e	74.51 e
S_3A_0	56.58 i	60.56 j	64.00 j
S_3A_1	58.01 h	61.47 i	64.82 i
S_3A_2	58.63 h	62.46 h	65.86 h
$LSD_{(0.05)}$	1.032	0.5459	0.6320
Significant level	**	*	*
CV (%)	4.61	4.74	4.81

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, * significant at 5% level of probability

4.2 Number of leaves $plant^{-1}$

4.2.1 Effect of salinity

Salinity had significant effect on number of leaves $plant^{-1}$ of wheat 60 DAS (Table 4 and Appendix IV). The highest number of leaves $plant^{-1}$ 12.97 was observed from the S_0 and the lowest number of leaves $plant^{-1}$ 9.89 was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil which is statistically similar with S_2 (10.37). This results agreed with Farahbakhsh and Saiid (2011) who reported that leaf number was also affected significantly by salinity and the highest concentration of salinity (12 dS m^{-1}) restricted leaf number and reduced it to one fourth of the control. Salinity generally provides a slow growth and development of cells, especially in the leaves which is confirmed by Munns (2002) who stated salinity reduces plant growth through lessening or stopping the leaf expansion. This factor suppresses the turgor pressure and metabolic activities in the cells that are observed as low number and small size of leaves associated with short plant height.

Table 4. Effect of different levels of salinity on number of leaves $plant^{-1}$, number of tillers $plant^{-1}$ and number of effective tillers $plant^{-1}$ of wheat

Treatment	Number of leaves $plant^{-1}$	Number of tillers $plant^{-1}$	Number of effective tillers $plant^{-1}$
S_0	12.97 a	2.99 a	2.55 a
S_1	11.35 b	2.55 b	2.25 b
S_2	10.37 c	2.36 b	1.86 c
S_3	9.89 c	2.02 c	1.54 d
$LSD_{(0.05)}$	0.587	0.194	0.197
Significant level	**	**	**
CV (%)	6.35	9.50	11.58

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

** Significant at 1% level of probability, NS- Not Significant

4.2.2 Effect of salicylic acid

Application of salicylic acid had showed significant effect on number of leaves $plant^{-1}$ of wheat 60 DAS (Table 5 and Appendix IV). The maximum number of leaves $plant^{-1}$ 11.86 was found from A_2 or 0.4 mM SA whereas the minimum number of leaves $plant^{-1}$ 10.44 was observed from A_0 or control.. Farahbakhsh and Saiid (2011) who reported that high concentration of SA (200 ppm) caused an increase of 74.94% in leaf area and number of leaf. Zhou *et al.* (1999) also indicate that SA increases the leaf area in sugarcane plants, which is consistent with our results.

Table 5. Effect of different concentration of salicylic acid on number of leaves plant^{-1}, number of tillers plant^{-1} and number of effective tillers plant^{-1} of wheat

Treatment	Number of leaves plant^{-1}	Number of tillers plant^{-1}	Number of effective tillers plant^{-1}
A_0	10.44 c	2.25 c	1.88 b
A_1	11.13 b	2.47 b	2.03 b
A_2	11.86 a	2.72 a	2.24 a
$LSD_{(0.05)}$	0.509	0.169	0.170
Significant level	**	**	**
CV (%)	6.35	9.50	11.58

A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, NS- Not Significant

4.2.3 Interaction effect of salinity and salicylic acid

The combined effect of salinity and salicylic acid showed significant variation on number of leaves plant^{-1} of wheat at 60 DAS (Table 6 and Appendix IV). The combination of S_0A_2 gave the maximum number of leaves plant^{-1} 13.38 which is statistically similar with S_0A_0 (12.49), S_0A_1 (13.03) and S_1A_2 (12.43). The minimum number of leaves plant^{-1} 9.27 was recorded from S_3A_0 which is statistically similar with S_2A_0 (9.62) and S_3A_1 (9.92). Farahbakhsh and Saiid (2011) also stated that salinity had a negative effect on the number of leaves (25.6% reduction), while SA increased this trait. In contrast the dissimilar results were also reported by Szalai and Janda (2009) who applied 50 and 100 mM NaCl to corn seedlings (*Zea mays* L.) and observed no increase in the concentration of leaf SA.

Table 6. Interaction effect of different levels of salinity and salicylic acid on number of leaves plant^{-1}, number of tillers plant^{-1} and number of effective tillers plant^{-1} of wheat

Treatment	Number of leaves plant^{-1}	Number of tillers plant^{-1}	Number of effective tillers plant^{-1}
S_0A_0	12.49 a	2.93 ab	2.41 ab
S_0A_1	13.03 a	2.99 ab	2.53 ab
S_0A_2	13.38 a	3.06 a	2.70 a
S_1A_0	10.38 bc	2.06 de	1.96 cd
S_1A_1	11.22 b	2.53 c	2.19 bc
S_1A_2	12.43 a	3.05 a	2.59 a
S_2A_0	9.62 cd	2.05 de	1.75 de
S_2A_1	10.34 bc	2.36 cd	1.88 cd
S_2A_2	11.14 b	2.66 bc	1.96 cd
S_3A_0	9.27 d	1.94 e	1.41 e
S_3A_1	9.92 cd	2.02 e	1.53 e
S_3A_2	10.47 bc	2.12 de	1.69 de
$LSD_{(0.05)}$	1.017	0.337	0.340
Significant level	**	*	**
CV (%)	6.35	9.50	11.58

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, * significant at 5% level of probability

4.3 Number of tiller plant^{-1}

4.3.1 Effect of salinity

Number of tiller plant^{-1} of wheat significantly influenced by different levels of salinity at 60 DAS (Table 4 and Appendix IV). The highest number of tiller plant^{-1} 2.99 was recorded from the S_0 and the lowest number of tiller plant^{-1} 2.02 was recorded from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. El-Hendawy *et al.* (2005) reported that tiller number of wheat was affected more by salinity than leaf number and leaf area at the vegetative stage.

4.3.2 Effect of salicylic acid

Application of salicylic acid had showed significant effect on number of tiller plant^{-1} of wheat at 60 DAS (Table 5 and Appendix IV). The maximum number of tiller plant^{-1} 2.72 was found from A_2 0.4 mM SA whereas the minimum number of tiller plant^{-1} 2.25 was observed from A_0 or control. Similarly Shakirova *et al.* (2003) found that the positive effect of SA on number of tillers plant^{-1} of wheat can be due to its influence on the other plant hormones. Azimi *et al.* (2013) also reported that SA had significantly effects on number of tiller per m^2 and maximum tiller was observed at 1.5mM across SA treatments.

4.3.3 Interaction effect of salinity and salicylic acid

Interaction of salinity and salicylic acid showed significant variation on number of tillers plant^{-1} of wheat at 60 DAS (Table 6 and Appendix IV). The combination of S_0A_2 gave the maximum number of tiller plant^{-1} 3.06 which is statistically similar with S_0A_0 (2.93), S_0A_1 (2.99) and S_1A_2 (3.05) whereas the minimum number of tiller plant^{-1} 1.94 was recorded from S_3A_0 which is statistically similar with S_2A_0 (2.05), S_3A_1 (2.02) and S_3A_2 (2.12). According to Shakirova *et al.* (2003) the positive effect of SA on growth can be due to its influence on the other plant hormones. SA altered the auxin, cytokinin and ABA balances in wheat and increased the growth under normal condition and improved the growth and salinity tolerance under saline condition.

4.4 Number of effective tiller plant^{-1}

4.4.1 Effect of salinity

Number of effective tiller plant^{-1} significantly influenced different levels of salinity of wheat at 60 DAS (Table 4 and Appendix IV). The maximum number of effective tiller plant^{-1} 2.55 was found from the S_0 and the lowest number of effective tiller plant^{-1} 1.54 was found from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. This result agreed with Ali (2004) who stated that number of productive tillers and all the genotypes were reduced by salinity. BINA (2008) reported that wheat varieties of high yielding and tolerant group recorded a higher value of number of effective tillers plant^{-l}.

4.4.2 Effect of salicylic acid

Application of salicylic acid had showed significant effect on number of effective tiller plant^{-1} of wheat at 60 DAS (Table 5 and Appendix IV). The highest number of effective tiller plant^{-1} 2.24 was observed from A_2 or 0.4 mM SA whereas the lowest number of effective tiller plant^{-1} 1.88 was observed from A_0 or control which was statistically similar with A_1 (2.03). Azimi *et al.* (2013) reported that SA had significantly effects on number of effective tiller per m^2 and maximum effective tiller was observed at 1.5mM across SA treatments.

4.4.3 Interaction effect of salinity and salicylic acid

Number of effective tiller plant^{-1} was significantly influenced by interaction of salinity and salicylic acid at 60 DAS (Table 6 and Appendix IV). The maximum number of effective tiller plant^{-1} 2.70 was observed from S_0A_2 which is statistically similar with S_0A_0 (2.4), S_0A_1 (2.53) and S_1A_2 (2.59). The minimum number of effective tiller plant^{-1} 1.41 was recorded from S_3A_0 which is statistically similar with S_2A_0 (1.75), S_3A_1 (1.53) and S_3A_2 (1.69).

4.5 SPAD value

4.5.1 Effect of salinity

SPAD value was not significantly influenced by different levels of salinity (Table 7 and Appendix IV). But numerically the highest SPAD value 37.09 was found from S_0 whereas the lowest 35.87 was found from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. This result disagreed with Yamane *et al.* (2004) reported the reduction in chlorophyll by salt stress and concluded that these results induced injury in chloroplasts is dependent on light and that H_2O_2 and OH are responsible for the deleterious effects of salt stress on chlorophyll content. Salinity treatment is known to affect photosynthetic pigments due to the retardation of their synthesis or the induction of degradation during salt stress (Misra *et al.*, 1997).

Table 7. Effect of different levels of salinity on SPAD value of wheat

Treatment	SPAD value
S_0	37.09
S_1	35.74
S_2	35.02
S_3	35.87
$LSD_{(0.05)}$	2.108
Significant level	NS
CV (%)	3.34

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
NS- Not Significant

4.5.2 Effect of salicylic acid

Application of salicylic acid had showed insignificant effect on SPAD value of wheat (Table 8 and Appendix IV). But numerically the highest SPAD value 36.32 was observed from A_2 whereas the lowest SPAD value 35.33 was observed from A_0 or control. The SPAD value of wheat increased with increasing the application of salicylic acid. In turn, the highest amount of SA application was accompanied with 38.66% increase in chlorophyll concentration in the leaves. The metabolic effects of SA depends on the plant type, the amount and the application method of that and in wheat 10^{-5} M SA increased the amount of photosynthetic pigments while the higher concentrations decreased it (Hayat and Ahmad, 2007).

Table 8. Effect of different concentration of salicylic acid on SPAD value of wheat

Treatment	SPAD value
A_0	37.09
A_1	35.74
A_2	35.02
$LSD_{(0.05)}$	2.108
Significant level	NS
CV (%)	3.34

A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
NS- Not Significant

4.5.3 Interaction effect of salinity and salicylic acid

SPAD value was not significantly influenced by interaction of salinity and salicylic acid (Table 9 and Appendix IV). But numerically the maximum SPAD value 37.49 was observed from S_0A_2 and the minimum SPAD value 34.46 was recorded from S_2A_0 treatment. These results are disagreement by Digdem *et al.* (2007) reported that the SA foliar application was increased pigments content , *chl* a, b and carotenoids under salinity conditions. Moreover, Khan *et al.* (2003) showed that SA increased photosynthetic rate in corn and soybean.

Table 9. Interaction effect of different levels of salinity and salicylic acid on SPAD value of wheat

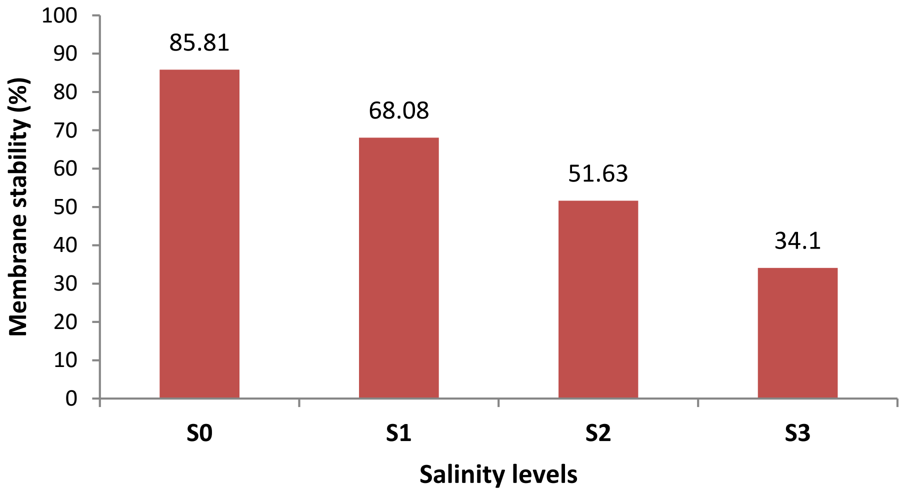
Treatment	SPAD value
S_0A_0	36.52
S_0A_1	37.26
S_0A_2	37.49
S_1A_0	35.34
S_1A_1	35.78
S_1A_2	36.10
S_2A_0	34.46
S_2A_1	35.10
S_2A_2	35.49
S_3A_0	35.03
S_3A_1	36.40
S_3A_2	36.19
$LSD_{(0.05)}$	3.652
Significant level	NS
CV (%)	3.34

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
NS- Not Significant

4.6 Membrane stability (%)

4.6.1 Effect of salinity

Membrane stability (%) was significantly influenced by different levels of salinity (Figure 1 and Appendix V). The maximum membrane stability 85.81 % was recorded from S_0 treatment whereas the minimum 34.10 % was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The percentage of membrane stability of wheat decreased with increasing the salinity level. Salinity reduced the osmotic potential as compared to untreated control (Chinnusamy and Zhu, 2003) which might result in decreased water availability.

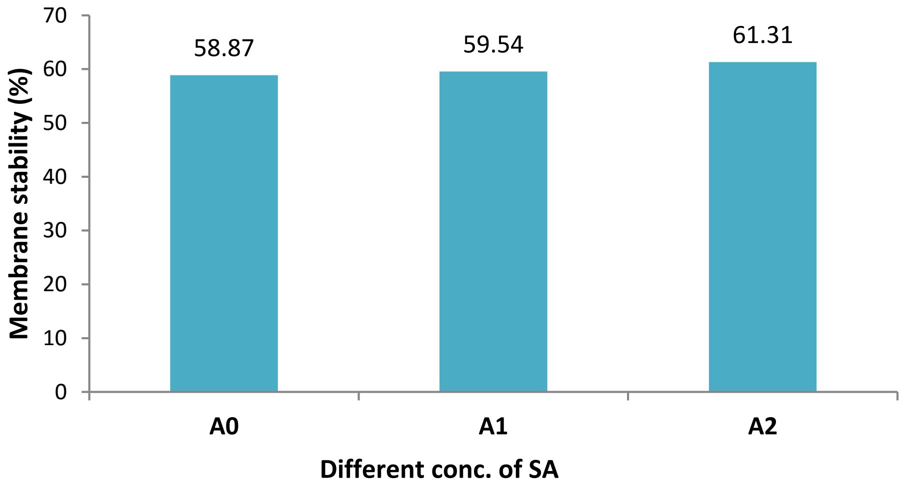


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 1. Effect of different levels of salinity on membrane stability (%) of wheat ($LSD_{0.05}$ = 2.285)

4.6.2 Effect of salicylic acid

The percentage of membrane stability was significantly affected by different concentration of salicylic acid (Figure 2 and Appendix V). The highest membrane stability 61.31 % was observed from A_2 or 0.4mM SA which was statistically similar with A_1 (59.54 %) whereas the lowest mitigation 58.87 % was observed from A_0. The membrane stability percentage of wheat increased with increasing the application of salicylic acid. SA has effectively increased the osmotic potential under salinity stress which is essential to restore the cell turgor. Chinnusamy and Zhu (2003) have suggested that plant survival depend on maintaining a positive turgor, which is indispensable for expansion growth of cells and stomatal opening. The stimulatory effect of SA was also recorded on the membrane stability index. The integrity and functions of biological membranes are very sensitive to environmental stress and stress-induced damage to membranes has been well documented in the plants (Nishida and Murata, 1995). Application of SA increases the accumulation of Ca^{+2} which can maintain membrane integrity (Khan *et al*., 2010).

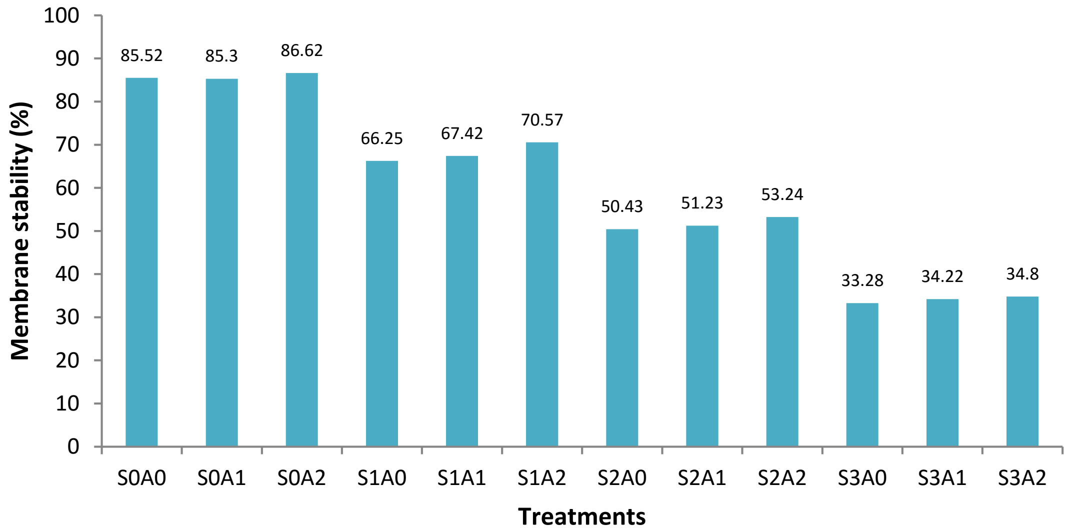


A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 2. Effect of different concentration of salicylic acid on membrane stability (%) of wheat ($LSD_{0.05}$ = 1.979)

4.6.3 Interaction effect of salinity and salicylic acid

Interaction effect of salinity and salicylic acid showed significant variation on the membrane stability percentage of wheat (Figure 3 and Appendix V). The highest membrane stability 86.62 % was observed from S_0A_2 which was statistically similar with S_0A_0 (85.52 %) and S_0A_1 (85.30 %). The lowest membrane stability 34.22 % was recorded from S_3A_1 treatment was statistically similar with S_3A_0 (33.28 %) and S_3A_2 (34.80 %). Fahad and Bano (2012) reported that salinity significantly decreased the osmotic potential as well as membrane stability index of maize leaves respectively as compared to unstressed control. However, SA application ameliorated the adverse effect of salinity on osmotic potential as well as membrane stability index (MSI). Lower amount of ion leakage (high MSI) indicates the stability of leaf membrane (Jaleel *et al*., 2007). SA treatment ameliorates the impact of abiotic stress through improving antioxidant system necessary to reduce oxidative damage and ion leakage from membranes (Yusuf *et al*., 2008).



S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 3. Combined effect of different levels of salinity and salicylic acid on membrane stability (%) of wheat ($LSD_{0.05}$ = 0.928)

4.7 Fresh weight plant^{-1} (g)

4.7.1 Effect of salinity

Fresh weight plant^{-1} was significantly affected by different salinity levels at 60 DAS. Fresh weight plant^{-1} decreased with increasing concentration of salinity in wheat (Table 10 and Appendix IV). The highest fresh weight plant^{-1} 11.60 g was recorded from control, S_0 (without salt) affected plant whereas the lowest 8.85 g was recorded from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil.. This result is in accordance with Singla and Garg (2005). Plant fresh weight decreased as a result of soil application of 50 mM NaCl, whereas Na^+ content increased. This is in accordance with findings in experiments on strawberry (Kaya *et al.*, 2001), maize (Agami, 2013), mung bean (Khan *et al.*, 2014) and barley (Fayez and Bazaid 2014).

Table 10. Effect of different levels of salinity on fresh weight plant^{-1}, dry weight plant^{-1} and 1000 grain weight of wheat

Treatment	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)	1000 grains weight (g)
S_0	11.60 a	4.38 a	51.08 a
S_1	10.69 b	3.85 b	47.96 b
S_2	9.82 c	3.41 c	45.01 c
S_3	8.85 d	3.22 d	26.70 d
$LSD_{(0.05)}$	0.046	0.026	0.026
Significant level	**	**	*
CV (%)	6.89	16.30	4.13

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
** significant at 1% level of probability, * significant at 5% level of probability

4.7.2 Effect of salicylic acid

Different concentration of salicylic acid had significant influenced on fresh weight plant^{-1} (g) of wheat at 60 DAS (Table 11 and Appendix IV). The maximum fresh weight plant^{-1} 10.59 g was observed from A_2 or 0.4 mM SA whereas the minimum fresh weight plant^{-1} 9.88 g was observed from A_0 or control. The fresh weight plant^{-1} of wheat increased with increasing the application of salicylic acid. Foliar applied salicylic acid enhanced vegetative growth by increasing fresh and dry biomass. These findings correlate with those of El-Tayeb (2005) and Gautam and Singh (1995) who documented that foliar applied SA enhanced biomass production in barley and wheat.

Table 11. Effect of different concentration of salicylic acid on fresh weight plant^{-1}, dry weight plant^{-1} and 1000 grain weight of wheat

Treatment	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)	1000 grains weight (g)
A_0	9.88 c	3.53 c	41.23 c
A_1	10.24 b	3.72 b	42.67 b
A_2	10.59 a	3.90 a	44.16 a
$LSD_{(0.05)}$	0.039	0.023	0.023
Significant level	**	**	**
CV (%)	6.89	16.30	4.13

A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, NS- Not Significant

4.7.3 Interaction effect of salinity and salicylic acid

The fresh weight plant^{-1} (g) of wheat showed a significant variation due to the combined effect of salt and salicylic acid at 60 DAS (Table 12 and Appendix IV). The maximum fresh weight plant^{-1} 12.15 g was observed from S_0A_2 while the minimum fresh weight plant^{-1} 8.64 g was recorded from S_3A_0 treatment. These findings correlate with those of El-Tayeb (2005) and Gautam and Singh (1995) who documented that the increase in growth biomass in response to SA under salinity stress may be due to protective role of SA on membranes that might be responsible for increasing plant salt tolerance.

Table 12. Interaction effect of different levels of salinity and salicylic acid on fresh weight plant^{-1}, dry weight plant^{-1} and 1000 grain weight of wheat

Treatment	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)	1000 grains weight (g)
S_0A_0	10.92 d	4.09 d	49.43 d
S_0A_1	11.72 b	4.46 b	51.20 b
S_0A_2	12.15 a	4.60 a	52.60 a
S_1A_0	10.36 f	3.61 f	46.31 f
S_1A_1	10.59 e	3.80 e	47.61 e
S_1A_2	11.12 c	4.14 c	49.95 c
S_2A_0	9.60 i	3.26 ij	43.97 i
S_2A_1	9.88 h	3.42 h	44.87 h
S_2A_2	9.98 g	3.56 g	46.20 g
S_3A_0	8.64 l	3.14 k	25.21 l
S_3A_1	8.78 k	3.22 j	27.00 k
S_3A_2	9.11 j	3.31 i	27.90 j
$LSD_{(0.05)}$	0.079	0.045	0.045
Significant level	*	*	**
CV (%)	6.89	16.30	4.13

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, * significant at 5% level of probability

4.8 Dry weight plant^{-1} (g)

4.8.1 Effect of salinity

Dry weight plant^{-1} was significantly affected by different salinity levels at 60 DAS. Dry weight plant^{-1} decreased with increasing concentration of salinity in wheat (Table 10 and Appendix V). The highest dry weight plant^{-1} 4.38 g was recorded from control, S_0 (without salt) treated plant whereas the lowest (3.22 g) was recorded from S_3 salinity level or addition of NaCl 9.0 g kg^{-1}

soil. This result similar with Farahbakhsh and Saiid (2011) who stated that salinity and salicylic acid independently affected shoot dry weight. With increasing salinity to 12 dS m^{-1}, shoot dry weight decreased by 80% compared to the control. Memon *et al.* (2007) stated that increasing water salinity progressively decreased fodder yield (fresh and dry weight) per plant.

4.8.2 Effect of salicylic acid

Different concentration of salicylic acid had significant influenced on dry weight $plant^{-1}$ (g) of wheat at 60 DAS (Table 11 and Appendix V). The maximum dry weight $plant^{-1}$ 3.90 g was observed from A_2 or 0.4 mM SA whereas the minimum dry weight $plant^{-1}$ 3.53 g was observed from A_0. The dry weight $plant^{-1}$ of wheat increased with increasing the application of salicylic acid. Farahbakhsh and Saiid (2011) reported that shoot dry weight increased with increasing salicylic acid (SA) concentration. It can be concluded that SA motivates the plant productivity and among the SA treatments, 200 ppm effectively increased shoot dry weight by 84%.

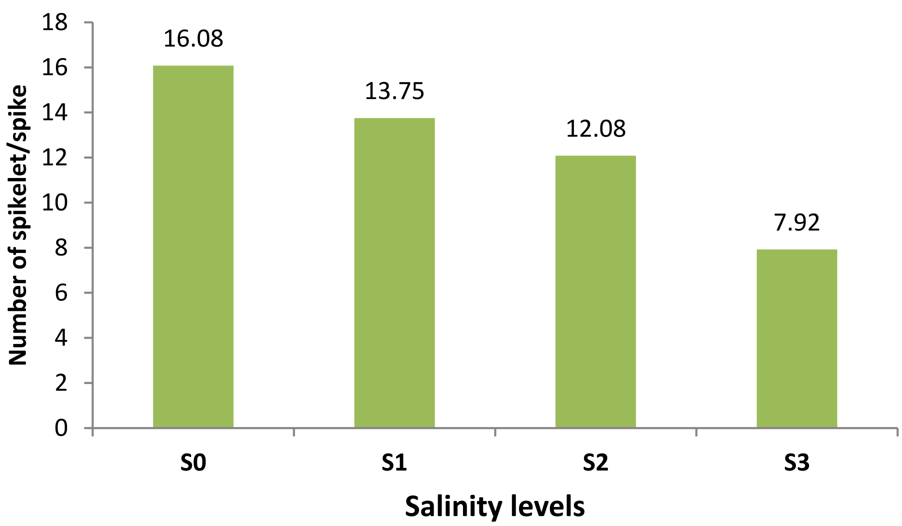
4.8.3 Interaction effect of salinity and salicylic acid

The dry weight $plant^{-1}$ (g) of wheat at 60 DAS showed a significant variation due to the combined effect of salt and salicylic acid (Table 12 and Appendix V). The maximum dry weight $plant^{-1}$ 4.60 g was observed from S_0A_2 while the minimum dry weight $plant^{-1}$ 3.14 g was recorded from S_3A_0 treatment. Growth reduction under saline condition has been well documented in various plants by many researchers such as Bengu (2012). Alleviated the deleterious effects of salinity by SA, GA_3 and Si was studied by many author. Levent *et al* (2007), Gunes *et al.* (2007) and Fahad and Asha, (2012), pointed out that addition of SA to maize plants grown in salt affected soil was significantly increased dry matter yield. Increases in dry matter and yield of salt stressed plant in response to SA may be related to induction of antioxidant response and protective role of membranes that increase the tolerance of plant to damage (Gunes *et al.*, 2007).

4.9 Number of spikelet spike^{-1}

4.9.1 Effect of salinity

A significant variation was recorded due to the different levels of salinity for the number of spikelet spike^{-1} of wheat (Figure 4 and Appendix V). The maximum number of spikelet spike^{-1} 16.08 was recorded for the S_0 treatment or control and the lowest 7.92 was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The number of spikelet spike^{-1} of wheat decreased with increasing the salinity level. Qiu *et al.* (2013) reported that high salinity stress produced 37% grain yield loss per plant that's attributed to shorten spike length which produced less number of spikelet per spike and shrunk grain in wheat experiment. Gain *et al.* (2004) reported that number of spikelet spike^{-1} decreased with increasing salinity levels. This statement was supported many workers (Ahmed *et al.*, 1980; Islam *et al.*, 1998; Islam, 2004 and Hossain, 2006).

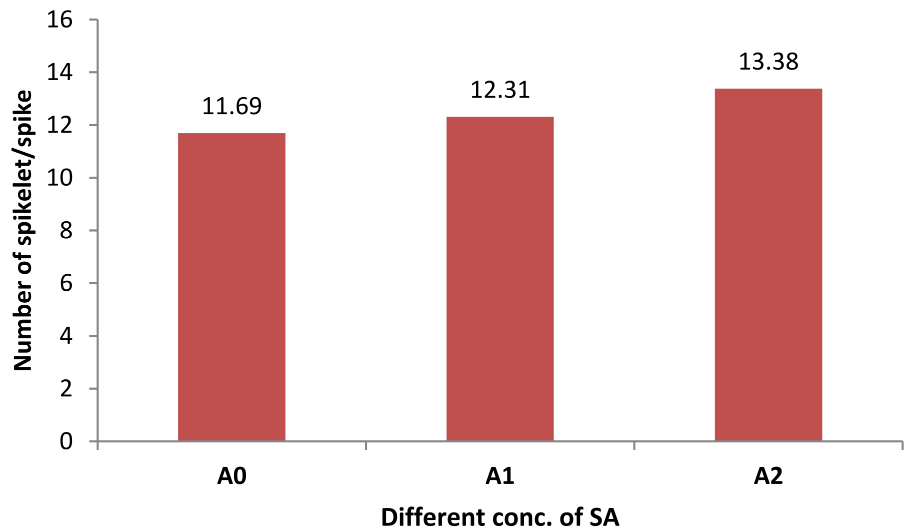


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 4. Effect of different levels of salinity on number of spikelet spike^{-1} of wheat ($LSD_{0.05}$ = 0.530)

4.9.2 Effect of salicylic acid

Application of salicylic acid had significant variation on the number of spikelet spike^{-1} of wheat (Figure 5 and Appendix V). The maximum number of spikelet spike^{-1} 13.38 was observed from A_2 or 0.4 mM SA whereas the minimum number of spikelet spike^{-1} 11.69 was observed from A_0. The number of spikelet spike^{-1} of wheat increased with increasing the application of salicylic acid. Aldesuquy *et al.* (2012) stated that mechanism of SA induced yield enhancement might be an increase in the number of spikelets because SA has the capacity to both directly or indirectly regulate yield. These results are in a good agreement with those obtained by Khan *et al*. (2003) with maize and soybean.

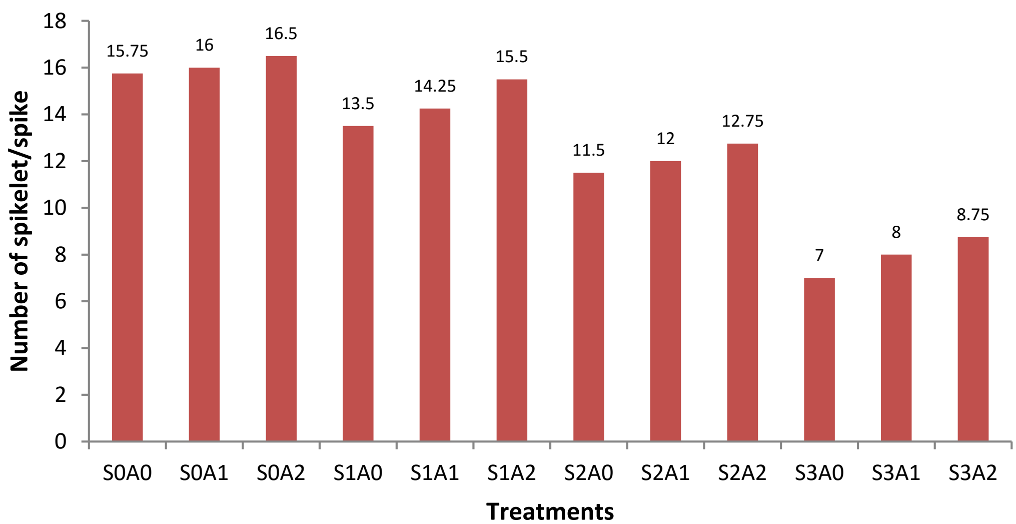


A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 5. Effect of different concentration of salicylic acid on number of spikelet spike^{-1} of wheat ($LSD_{0.05}$ = 0.459)

4.9.3 Interaction effect of salinity and salicylic acid

Interaction of salinity and salicylic acid showed significant variation on the number of spikelet spike^{-1} of wheat (Figure 6 and Appendix V). The highest number of spikelet spike^{-1} 16.50 was observed from S_0A_2 which was statistically similar S_0A_0 (15.75) and S_0A_1 (16.00) while the lowest 7.00 was recorded from S_3A_0 treatment. The application of salicylic acid (0.04 mM) enhanced the yield and yield components of the wheat. In this respect, Aldesuquy *et al.* (2012) and Arfan *et al*. (2007) studied the effect of exogenous application of salicylic acid (SA) through the rooting medium of two wheat cultivars differing in salinity tolerance. They found that increase number of spikelets per spike with 0.25mM SA application under saline conditions suggested that improvement in salt-induced reduction in grain yield with SA application was mainly due to increase in grain size and number.



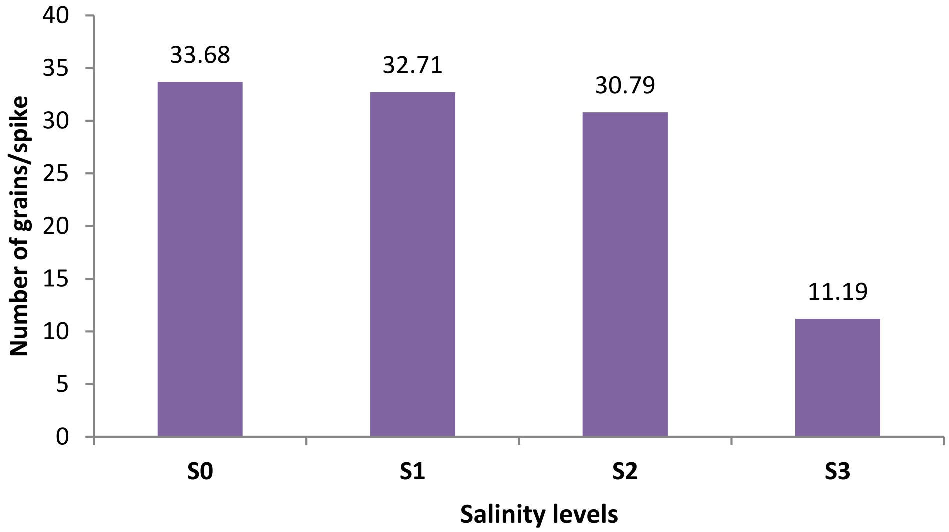
S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 6. Combined effect of different levels of salinity and salicylic acid on number of spikelet spike^{-1} of wheat ($LSD_{0.05}$ = 0.918)

4.10 Number of grains spike^{-1}

4.10.1 Effect of salinity

A significant variation was recorded due to the different levels of salinity for the number of grains spike^{-1} of wheat (Figure 7 and Appendix V). The maximum number of grains spike^{-1} 33.68 was recorded for the S_0 treatment and the minimum 11.19 was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The number of grains spike^{-1} of wheat decreased with increasing the salinity level. The similar results found by El-Hendawy *et al.* (2005) who reported that grain number of wheat was decreased with increasing salinity levels.

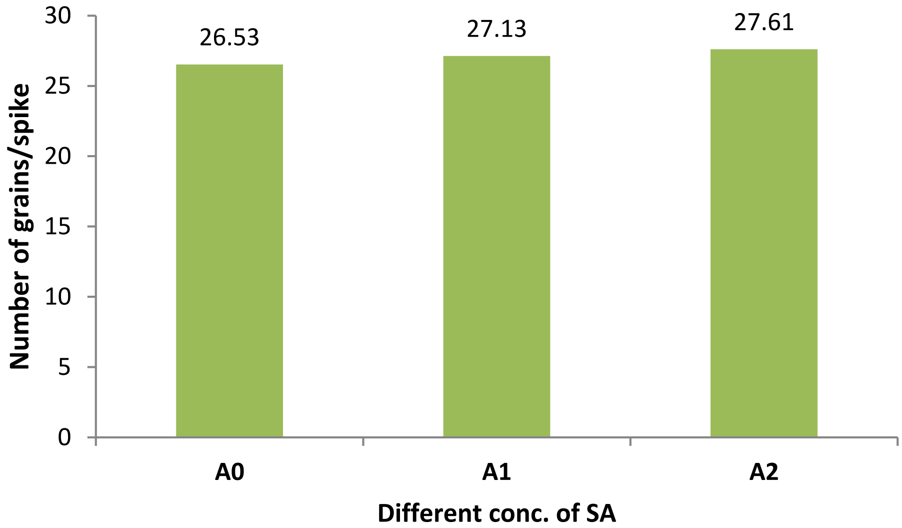


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 7. Effect of different levels of salinity on number of grains spike^{-1} of wheat ($LSD_{0.05}$ = 0.091)

4.10.2 Effect of salicylic acid

The number of grains spike^{-1} was significantly affected by different concentration of salicylic acid (Figure 8 and Appendix V). The maximum number of grains spike^{-1} 27.61 was observed from A_2 or 0.4 mM SA whereas the minimum number of grains spike^{-1} 26.53 was observed from A_0. The number of grains spike^{-1} of wheat increased with increasing the application of salicylic acid. Aldesuquy *et al.* (2012) stated that mechanism of SA induced yield enhancement might be an increase in the number of grains because SA has the capacity to both directly or indirectly regulate yield. These results are in a good agreement with those obtained by Khan *et al*. (2003) with maize and soybean.



A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 8. Effect of different concentration of salicylic acid on number of grains spike^{-1} of wheat ($LSD_{0.05}$ = 0.079)

4.10.3 Interaction effect of salinity and salicylic acid

Combined effect of salinity and salicylic acid showed significant variation on the number of grains spike^{-1} of wheat (Figure 9 and Appendix V). The highest number of grains spike^{-1} 33.91 was observed from S_0A_2 whereas the lowest number of grains spike^{-1} 10.39 was recorded from S_3A_0 treatment. The application of salicylic acid (0.04 mM) enhanced the yield and yield components of the wheat. Arfan *et al*. (2007) stated that the effect of exogenous application of salicylic acid (SA) through the rooting medium of two wheat cultivars differing in salinity tolerance. They reported that increase in grain yield along with number of grains with 0.25mM SA application under saline conditions suggested that improvement in salt-induced reduction in grain yield with SA application was mainly due to increase in grain size and number.

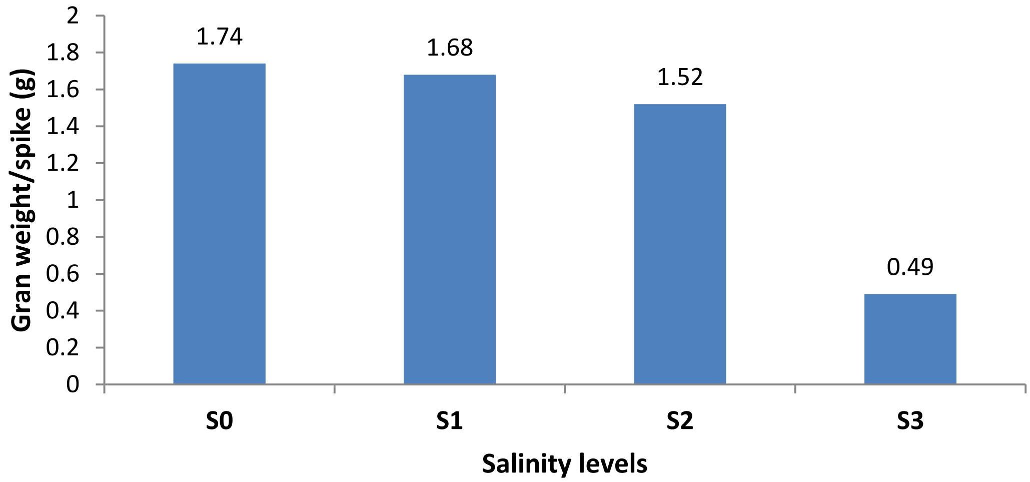
S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 9. Combined effect of different levels of salinity and salicylic acid on number of grains spike^{-1} of wheat ($LSD_{0.05}$ = 0.158)

4.11 Grain weight spike^{-1} (g)

4.11.1 Effect of salinity

A significant variation was recorded due to the different levels of salinity for grain weight spike^{-1} of wheat (Figure 10 and Appendix V). The maximum grain weight spike^{-1} 1.74 g was recorded for the S_0 treatment and the lowest 0.49 g was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil.

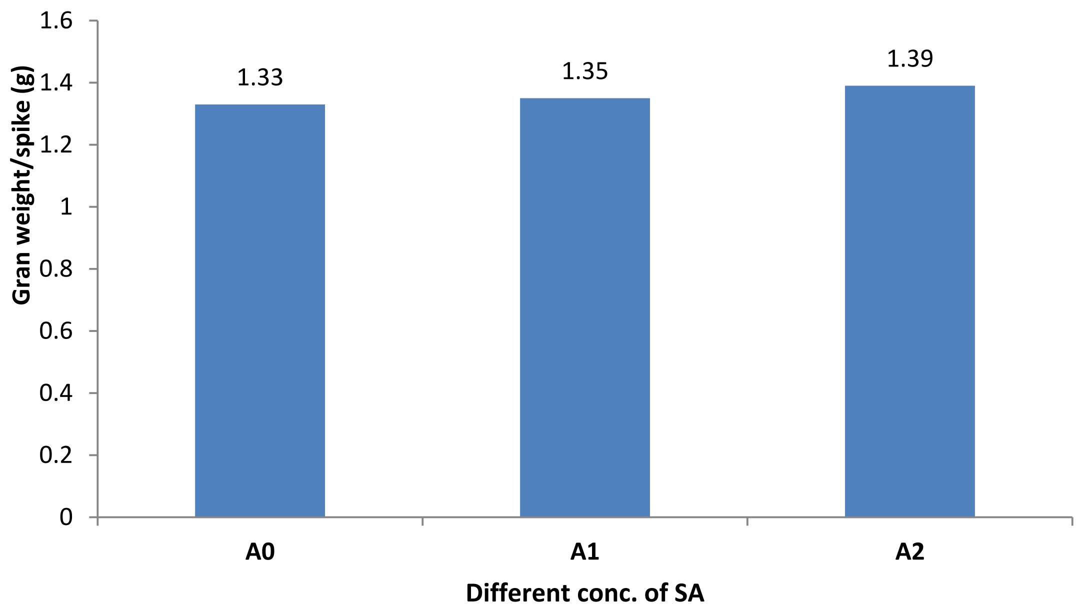


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 10. Effect of different levels of salinity on grain weight spike^{-1} of wheat ($LSD_{0.05}$ = 0.037)

4.11.2 Effect of salicylic acid

Different concentration of salicylic acid had significant variation on grain weight spike^{-1} (g) of wheat (Figure 11 and Appendix V). The maximum grain weight spike^{-1} 1.39 g was observed from A_2 or 0.4 mM SA whereas the minimum grain weight spike^{-1} 1.33 g was observed from A_0 or control which was statistically similar A_1 (1.35 g). The 1000 grains weight of wheat increased with increasing the application of salicylic acid. These results are similar to those of Zhou *et al*. (1999) who reported that maize stem injected with SA produced 9% more grain weight.

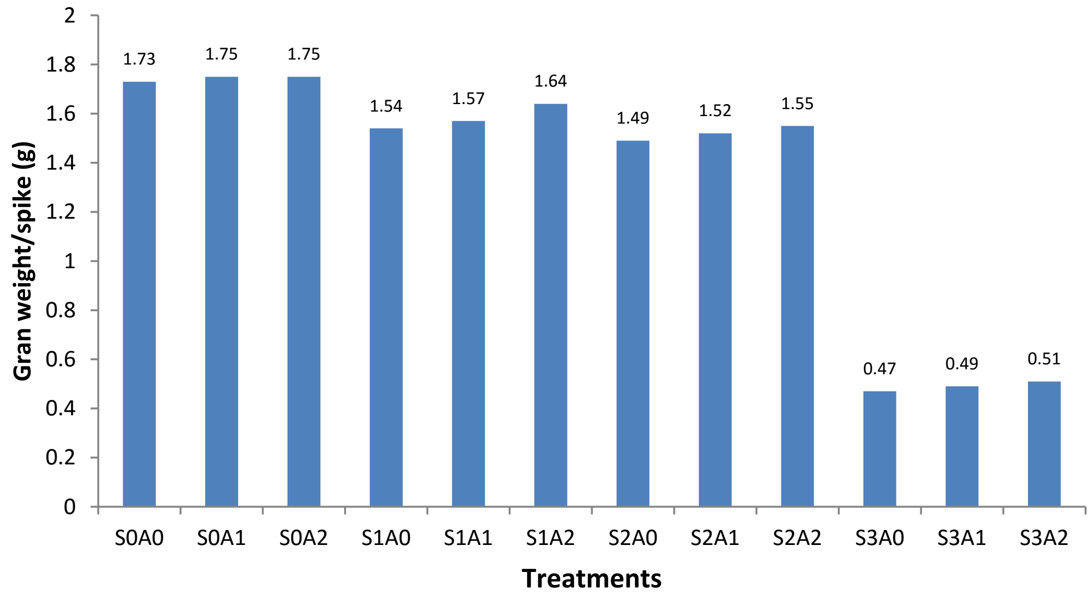


A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 11. Effect of different concentration of salicylic acid levels on grain weight spike^{-1} of wheat ($LSD_{0.05}$ = 0.032)

4.11.3 Interaction effect of salinity and salicylic acid

Interaction of salinity and salicylic acid showed significant variation on grain weight spike^{-1} (g) of wheat (Figure 12 and Appendix V). The highest grain weight spike^{-1} 1.75 g was observed from S_0A_2 which was statistically similar S_0A_0 (1.73 g) and S_0A_1 (1.75 g) while the lowest grain weight spike^{-1} 0.47 g was recorded from S_3A_0 treatment which was statistically similar S_3A_1 (0.49 g) and S_3A_2 (0.51 g).



S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 12. Combined effect of different levels of salinity and salicylic acid on grain weight spike^{-1} of wheat ($LSD_{0.05}$ = 0.064)

4.12 1000 grains weight (g)

4.12.1 Effect of salinity

1000 grains weight (g) was significantly influenced by different salinity levels. 1000 grains weight decreased with increasing concentration of salinity in wheat (Table 10 and Appendix IV). The highest 1000 grains weight 51.08 g was recorded from control, S_0 (without salt) treated plant whereas the lowest 0.43 g was recorded from S_2. The similar results found by El-Hendawy *et al.* (2005) who reported that 1000-grain weight of wheat was affected by salinity levels at maturity. Gain *et al.* (2004) reported that 1000-grain weight of wheat decreased with increasing salinity levels. This statement was supported many workers (Ahmed *et al.*, 1980; Islam *et al.*, 1998; Islam, 2004 and Hossain, 2006).

4.12.2 Effect of salicylic acid

Different concentration of salicylic acid had significant influenced on 1000 grains weight (g) of wheat (Table 11 and Appendix V). The maximum 1000 grains weight 44.16 g was observed from A_2 or 0.4 mM SA whereas the minimum 1000 grains weight 41.23 g was observed from A_0. The 1000 grains weight of wheat increased with increasing the application of salicylic acid. 1000 seed weight is one of the most important parts of final wheat yield and it is determined by rate and duration of grain filling. Rate of grain filling is highly depends on genotype but duration of grain filing in depends on environment (Quarrie and Jones, 1979). SA application increased 1000 seed weight and highest value was observed at 1.5 mM (Azimi *et al.,* 2013). SA can increase 1000 seed weight by some ways; one of them is change in photosynthesis, Zhou *et al.* (1999) reported that photosynthetic pigments were increased in corn with SA application. Moreover, Khan *et al.* (2003) showed that SA increased photosynthetic rate in corn and soybean.

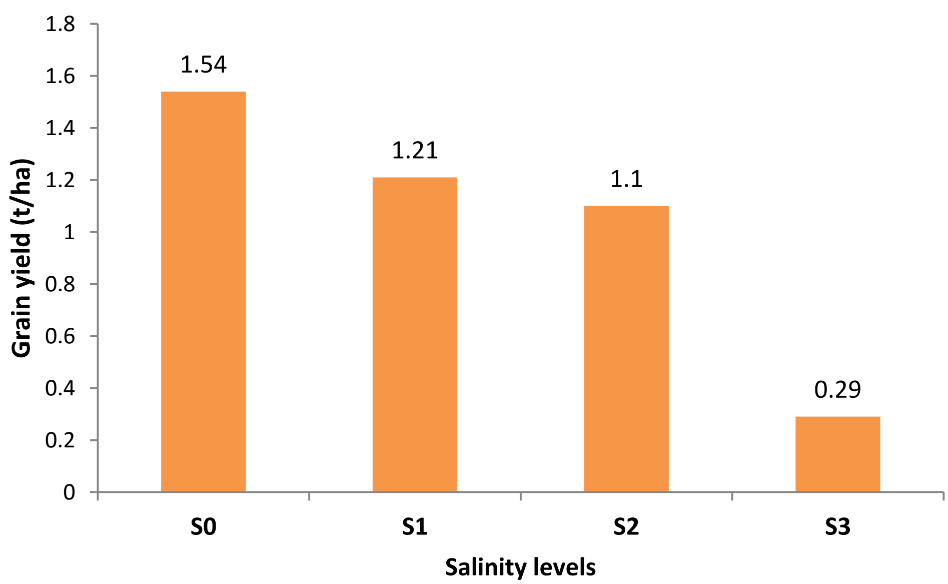
4.12.3 Interaction effect of salinity and salicylic acid

The 1000 grains weight (g) of wheat showed a significant variation due to the combined effect of salinity and salicylic acid (Table 12 and Appendix V). The highest 1000 grains weight 52.60 g was observed from S_0A_2 while the lowest 1000 grains weight 25.21 g was recorded from S_3A_0 treatment. Aldesuquy *et al.* (2012) reported that the application of salicylic acid (0.05 M) enhanced the yield and yield components of the two wheat cultivars. In this respect, Arfan *et al*. (2007) studied the effect of exogenous application of salicylic acid (SA) through the rooting medium of two wheat cultivars differing in salinity tolerance. They found that increase in grain yield along with increase in 1000 grain weight with 0.25mM SA application under saline conditions suggested that improvement in salt-induced reduction in grain yield with SA application was mainly due to increase in grain size and number.

4.13 Grain yield (t ha^{-1})

4.13.1 Effect of salinity

Significant variation was recorded for grain yield (t ha^{-1}) of wheat due to the different salinity levels (Figure 13 and Appendix V). The highest grain yield 1.54 t ha^{-1} was obtained from S_0 or control whereas the lowest 0.29 t ha^{-1} value from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The result showed the gradual decrease of yield with the increased levels of salinity. These results are consistent with the present morpho-physiological and yield contributing characters such as plant height (Table 1), number of leaves $plant^{-1}$, tillers $plant^{-1}$, effective tillers $plant^{-1}$ (Table 4), 1000 grain weight (Table 10), number of spikelet $spike^{-1}$ (Figure 4) and number of grains $spike^{-1}$ (Figure 7). In addition similar observation or reported by Aldesuquy *et al.* (2012) foliar application of SA appeared to alleviate the stress imposed by drought on all yield components of the two wheat cultivars. Salt stress of Ec 6dSm^{-1} and 10 dSm^{-1} decreased grain yields and harvest index (Afria and Nornolia, 1999; Asha and Dhingra, 2007). All together these results suggest that salt stress reduce the grain yield by changing the morpho-physiology in wheat.

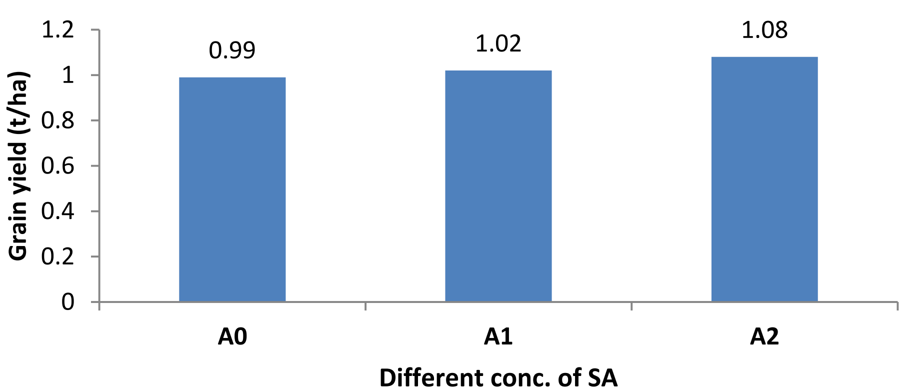


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 13. Effect of different levels of salinity on grain yield of wheat ($LSD_{0.05}$ = 0.037)

4.13.2 Effect of salicylic acid

In this study the grain yield of wheat (g) was converted into hectare^{-1} and has been expressed in metric tons (Figure 14 and Appendix V). The different concentrations of salicylic acid had significant effect on the grain yield of wheat ton hectare^{-1}. The highest grain yield 1.08 t ha^{-1} was observed from A_2 or 0.4 mM SA whereas the lowest grain yield 0.99 t ha^{-1} was observed from A_0. The grain yield of wheat increased with increasing the application of salicylic acid. These results are consistent with the present morpho-physiological and yield contributing characters such as plant height (Table 2), number of leaves plant^{-1}, tillers plant^{-1}, effective tillers plant^{-1} (Table 5), 1000 grain weight (Table 11), number of spikelet spike^{-1} (Figure 5) and number of grains spike^{-1} (Figure 8). In addition similar observation or reported by Larque-Saavedra, (1979) different levels of acetylsalicylic acid function as anti-transpirant and inhibit the opening of stomata. Salicylic acid also reverses the closure of stomata caused by abscisic acid (Rai *et al*., 1986). Exogenous application of salicylic acid improves the yield of crops (Singh and Kaur, 1980; Arfan *et al*., 2007). The influence of the SA treatment was dependent on the concentration which was used. Maximum yield was obtained at 1.5mM. SA application may result in stomatal closure, increased WUE, increased chlorophyll content, increased respiratory-pathways and intercellular CO_2 concentration, and stimulatory changes in other physiological and biochemical attributes (Ashraf *et al*., 2010). All together these results suggest that application of salicylic acid increased the grain yield by changing the morpho-physiology in wheat.

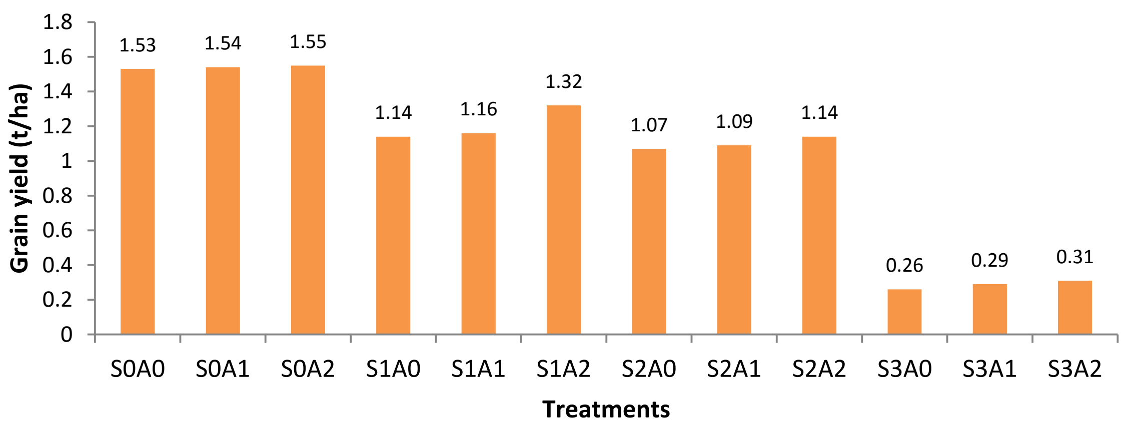


A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 14. Effect of different concentration of salicylic acid on grain yield of wheat ($LSD_{0.05}$ = 0.032)

4.13.3 Interaction effect of salinity and salicylic acid

There was a significant combined effect of different levels of salinity and salicylic acid concentrations and showed significant variation on the grain yield of wheat (Figure 15 and Appendix V). The maximum grain yield 1.55 t ha^{-1} was observed from S_0A_2 which was statistically similar with S_0A_0 (1.53 t ha^{-1}) and S_0A_1 (1.54 t ha^{-1}) while the lowest 0.26 t ha^{-1} was recorded from S_3A_0 treatment was statistically similar with S_3A_1 (0.29 t ha^{-1}). Previous results like plant height (Table 3), number of leaves $plant^{-1}$, tillers $plant^{-1}$, effective tillers $plant^{-1}$ (Table 6), 1000 grain weight (Table 12), number of spikelet $spike^{-1}$ (Figure 6) and number of grains $spike^{-1}$ (Figure 9) had similarly with these results. Gunes *et al.* (2007) reported that SA could be used as a potential growth regulator to improve plant salinity tolerance. Other authors reported increases in fruit yield (Yildirim and Dursan, 2008) after SA application. However, SA induces a wide range of metabolic responses that are generally directed toward adjusting the redox balance in the photosynthetic machinery under conditions of environmental stress. In the case of stress induced by salinity, adjustments are primarily made in the levels of antioxidant compounds that alleviate oxidative stress and these adjustments do not always result in an increase in fruit yield (Joseph *et al.*, 2010). All together these results suggest that combination of without salt and application of 0.4 Mm salicylic acid increased the grain yield by changing the morpho-physiology in wheat.



S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 15. Combined effect of different levels of salinity and salicylic acid on grain yield of wheat ($LSD_{0.05}$ = 0.064)

4.14 Straw yield (t ha^{-1})

4.14.1 Effect of salinity

Significant variation was recorded for straw yield (t ha^{-1}) of wheat due to the different salinity levels (Table 13 and Appendix V). The maximum straw yield 1.34 t ha^{-1} was obtained from S_0 whereas the lowest 0.46 t ha^{-1} value from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The result showed the gradual decrease of straw yield with the increased levels of salinity. These results are consistent with the present morpho-physiological and yield contributing characters such as plant height (Table 1), number of leaves $plant^{-1}$, tillers $plant^{-1}$, effective tillers $plant^{-1}$ (Table 4), fresh weight $plant^{-1}$ and dry weight $plant^{-1}$ (Table 10). In addition similar observation or reported by Shirazi *et al. (*2001) that yield and yield attributes decreased markedly with increasing levels of sodicity. Salt stress of Ec 6 dsm^{-1} and 10 dsm^{-1} decreased straw yields and harvest index (Afria and Nornolia, 1999; Asha and Dhingra, 2007). All together these results suggest that application of salicylic acid increased the straw yield by changing the morpho-physiology in wheat.

Table 13. Effect of different levels of salinity on straw yield, biological yield and harvest index of wheat

Treatment	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
S_0	1.34 a	2.88 a	53.50 a
S_1	1.04 b	2.25 b	53.69 a
S_2	0.96 c	2.06 c	53.44 a
S_3	0.46 d	0.75 d	38.30 b
$LSD_{(0.05)}$	0.026	0.059	0.46
Significant level	**	**	*
CV (%)	2.96	3.66	1.26

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
** significant at 1% level of probability, * significant at 5% level of probability

4.14.2 Effect of salicylic acid

The different concentrations of salicylic acid had significant effect on the straw yield of wheat (Table 14 and Appendix V). The highest straw yield 0.97 t ha^{-1} was observed from A_2 or 0.4 mM SA whereas the lowest 0.93 t ha^{-1} was observed from A_0 which was statistically similar with A_1 (0.95 t ha^{-1}). The straw yield of wheat increased with increasing the application of salicylic acid.

These results are consistent with the present morpho-physiological and yield contributing characters such as plant height (Table 2), number of leaves plant^{-1}, tillers plant^{-1}, effective tillers plant^{-1} (Table 5), fresh weight plant^{-1} and dry weight plant^{-1} (Table 11). In addition similar observation or stated by Aldesuquy, *et al.* (2012) that foliar application of SA appeared to alleviate the stress on straw yield of the two wheat cultivars. All together these results suggest that application of salicylic acid increased the straw yield by changing the morpho-physiology in wheat.

Table 14. Effect of different concentration of salicylic acid on straw yield, biological yield and harvest index of wheat

Treatment	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
A_0	0.93 b	1.92 c	49.14 c
A_1	0.95 b	1.97 b	49.67 b
A_2	0.97 a	2.05 a	50.39 a
$LSD_{(0.05)}$	0.023	0.051	0.402
Significant level	**	**	**
CV (%)	2.96	3.66	1.26

A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability

4.14.3 Interaction effect of salinity and salicylic acid

There was a significant combined effect of different levels of salinity and salicylic acid concentrations and showed significant variation on the straw yield of wheat (Table 15 and Appendix V). The maximum straw yield 1.35 t ha^{-1} was observed from S_0A_2 which was statistically similar with S_0A_0 (1.33 t ha^{-1}) and S_0A_1 (1.34 t ha^{-1}) while the lowest 0.44 t ha^{-1} was recorded from S_3A_0 treatment was statistically similar with S_3A_1 (0.46 t ha^{-1}) and S_3A_2 (0.48 t ha^{-1}). Previous results like plant height (Table 3), number of leaves plant^{-1}, tillers plant^{-1}, effective tillers plant^{-1} (Table 6), fresh weight plant^{-1} and dry weight plant^{-1} (Table 12) had similarly with these results. Salicylic acid (SA) is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in plants (Hayat *et al*., 2010) and also provides protection against biotic and abiotic stresses such as salinity (Kaya *et al.,* 2002). All together these results suggest that combination of without salt and application of 0.4 Mm salicylic acid increased the straw yield by changing the morpho-physiology in wheat.

Table 15. Interaction effect of different levels of salinity and salicylic acid on straw yield, biological yield and harvest index of wheat

Treatment	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
S_0A_0	1.33 a	2.86 b	53.50 b
S_0A_1	1.34 a	2.88 ab	53.51 b
S_0A_2	1.35 a	2.91 a	53.49 b
S_1A_0	1.01 cd	2.15 de	53.03 b
S_1A_1	1.02 c	2.18 d	53.16 b
S_1A_2	1.08 b	2.40 c	54.89 a
S_2A_0	0.94 e	2.01 f	53.17 b
S_2A_1	0.96 e	2.06 f	53.35 b
S_2A_2	0.97 de	2.11 e	53.81 b
S_3A_0	0.44 f	0.70 h	36.86 d
S_3A_1	0.46 f	0.75 g	38.63 c
S_3A_2	0.48 f	0.79 g	39.40 c
$LSD_{(0.05)}$	0.045	0.102	0.805
Significant level	**	*	**
CV (%)	2.96	3.66	1.26

S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA
** significant at 1% level of probability, * significant at 5% level of probability

4.15 Biological yield (t ha^{-1})

4.15.1 Effect of salinity

Biological yield was significantly influenced by different levels of salinity (Table 13 and Appendix V). The highest biological yield 2.88 t ha^{-1} was obtained from S_0 whereas the lowest 0.75 t ha^{-1} value from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The result showed the gradual decrease of biological yield with the increased levels of salinity. Kumar *et al*. (2012) stated that biological yield and harvest index were significantly reduced by salinity. Shirazi *et al. (*2001) reported that yield and yield attributes decreased markedly with increasing levels of sodicity. Salt stress of Ec 6 dsm^{-1} and 10 dsm^{-1} decreased grains, straw yield and harvest index (Afria and Nornolia, 1999; Asha and Dhingra, 2007).

4.15.2 Effect of salicylic acid

Biological yield was significantly affected by the different concentrations of salicylic acid of wheat (Table 14 and Appendix V). The highest biological yield 2.05 t ha^{-1} was observed from A_2 or 0.4 mM SA whereas the lowest 1.92 t ha^{-1} was observed from A_0 or control. The straw yield of wheat increased with increasing the application of salicylic acid. Similarly, foliar application of SA also caused increase in biological yield of wheat (Singh and Usha, 2003).

4.15.3 Interaction effect of salinity and salicylic acid

Interaction effect between different levels of salinity and salicylic acid concentrations was significant in respect of biological yield of wheat (Table 15 and Appendix V). The maximum 2.91 t ha^{-1} biological yield was observed from S_0A_2 which was statistically similar with S_0A_1 (2.88 t ha^{-1}) whereas the lowest biological yield 0.70 t ha^{-1} was recorded from S_3A_0 treatment. These results are in agreement with those of El-Tayeb (2005) and Arfan *et al*. (2007) who reported that exogenous foliar application of SA ameliorated the adverse effects of salt stress on growth and yield of barley and wheat, respectively. Similarly, foliar application of SA also caused increase in biological yield of wheat under water stress (Singh and Usha, 2003).

4.16 Harvest index (%)

4.16.1 Effect of salinity

Harvest index (%) was significantly influenced by different levels of salinity (Table 13 and Appendix V). The highest harvest index 53.69 % was obtained from S_1 which was statistically similar with S_0 (53.50 %) and S_2 (53.44 %) whereas the lowest 38.30 % value from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. Hossain (2002) stated that harvest index decreased with increase of salinity level in rice. Similar result was also reported by Islam (2004), Hossain (2006) and Rana (2007) in rice.

4.16.2 Effect of salicylic acid

Harvest index (%) was significantly affected by the different concentrations of salicylic acid of wheat (Table 14 and Appendix V). The highest harvest index 50.39 % was observed from A_2 or 0.4 mM SA whereas the lowest 49.14 % was observed from A_0. Results showed that, straw yield of wheat increased with increasing the application of salicylic acid. It has been proposed that SA treatment probably activate the consumption of soluble carbohydrates to form new cell constituents as a mechanism to promote plant growth and harvest index (Khodary, 2004). Azimi *et al.* (2013) also stated that SA treatments improved harvest index in wheat under drought stress that 1.5mM treatments of SA had maximum harvest index as compared with control and 0.75mM.

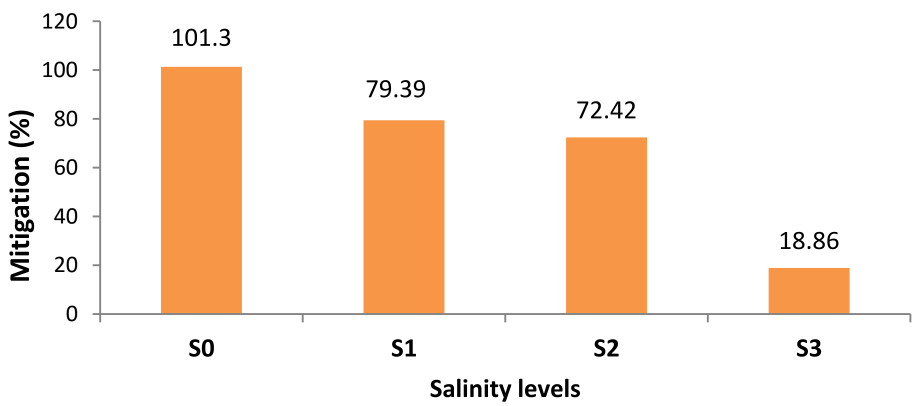
4.16.3 Interaction effect of salinity and salicylic acid

Interaction effect between different levels of salinity and salicylic acid concentrations was significant in respect of harvest index of wheat (Table 15 and Appendix V). The maximum 54.89 % harvest index was observed from S_1A_2 while the lowest harvest index 36.86 % was recorded from S_3A_0 treatment. The role of SA in defense mechanism to alleviate salt stress in plants was studied (Afzal *et al*., 2006; Hussein *et al*., 2007).

4.17 Mitigation (%)

4.17.1 Effect of salinity

Mitigation (%) was significantly influenced by different levels of salinity of wheat (Figure 16 and Appendix V). The maximum salt alleviation percentage 101.3 was recorded from S_0 treatment or control whereas the minimum 18.86 % was observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The percentage of mitigation of wheat decreased with increasing the salinity level.

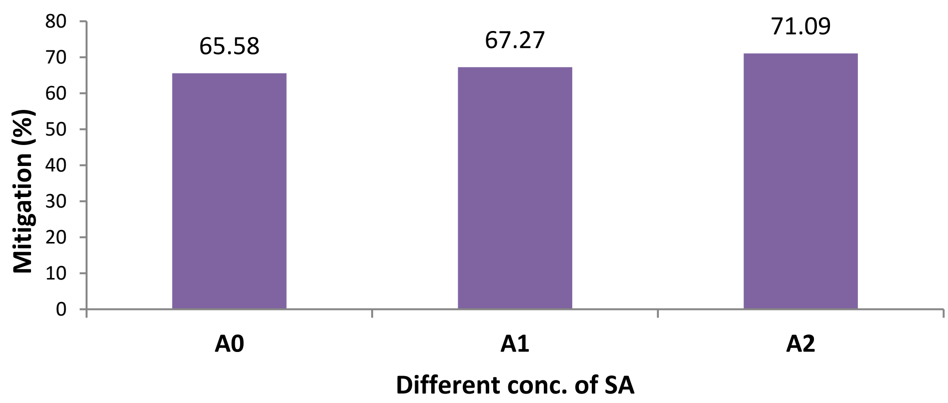


S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Figure 16. Effect of different levels of salinity on mitigation (%) of wheat ($LSD_{0.05}$ = 0.298)

4.17.2 Effect of salicylic acid

The percentage of mitigation was significantly affected by different concentration of salicylic acid (Figure 17 and Appendix V). The highest salt alleviation percentage 71.09 was observed from A_2 or 0.4 mM SA whereas the lowest salt alleviation percentage 65.58 was observed from A_0 or control. The mitigation percent of the yield of wheat increased with increasing the application of salicylic acid.

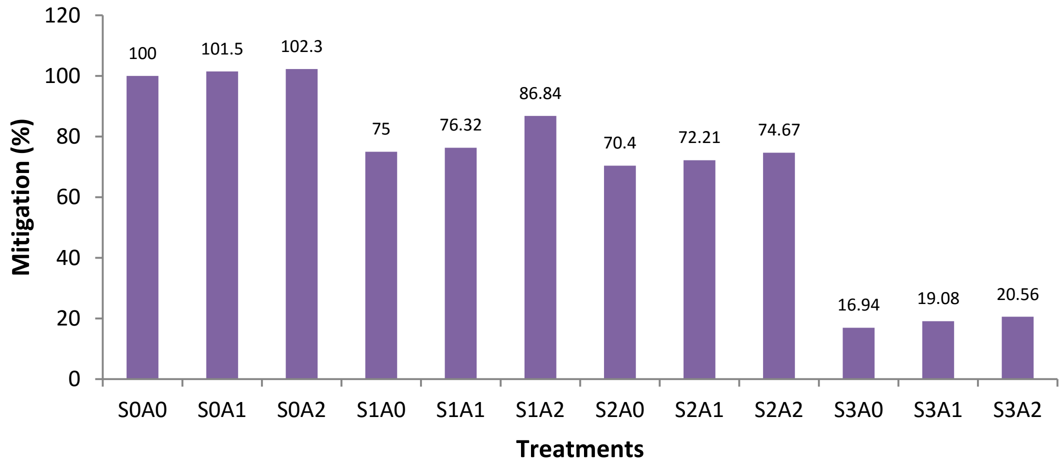


A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 17. Effect of different concentration of salicylic acid on mitigation (%) of wheat ($LSD_{0.05}$ = 0.260)

4.17.3 Interaction effect of salinity and salicylic acid

Combined effect of salinity and salicylic acid showed significant variation on the mitigation percentage of wheat (Figure 18 and Appendix V). The highest salt alleviation percentage 86.84 was observed from S_1A_2 while the lowest salt alleviation percentage 16.94 was recorded from S_3A_0 treatment. Considering the above results, it suggests that the interaction effect of different levels of salinity and salicylic acid can successfully alleviate the salt stress in wheat.



S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil
A_0 = No salicylic acid, A_1 = 0.2 mM SA, A_2 = 0.4 mM SA

Figure 18. Combined effect of different levels of salinity and salicylic acid on mitigation (%) of wheat ($LSD_{0.05}$ = 0.517)

CHAPTER V

SUMMARY AND CONCLUSIONS

The experiment was conducted in the Farm of Sher-e-Bangla Agricultural University, Dhaka, during the period from November 2014 to March 2015 to find out the mitigation of salt stress in wheat with salicylic acid. In this experiment, the treatments consisted of four different salinity levels viz. S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil ≈ 3-4 dSm^{-1}, S_2 = 6.0 g NaCl kg^{-1} of soil ≈ 7-8 dSm^{-1}, S_3 = 9.0 g NaCl kg^{-1} of soil ≈ 11-12 dSm^{-1} and three different levels of salicylic acid viz. A_0 = 0 mM, A_1= 0.2 mM and A_2 = 0.4 mM. The experiment was laid out in two factors Randomized complete Block Design (RCBD) with four replications. Data on different growth parameters, physiological parameters and yield with yield contributing characters of wheat were recorded. The collected data were statistically analyzed for evaluation of the treatment effect. A significant variation among the treatments was found while different salinity levels and salicylic acid levels were applied in different combinations.

There are significant differences among the influence of different levels of salinity in case of almost all the parameters. In this experiment, wheat plants were subjected to salinity by applying saline water at three different days in the life cycle of tomato plant to keep the soil in saline condition. Plant grown on normal soil (control treatment) showed the maximum height more or less over the growth period whereas the lowest height was recorded from 100 g kg^{-1} of soil treated plants. At 45, 60 DAS and at harvest, the highest plant height was 66.73 cm, 73.57 cm and 77.08 cm, respectively under a controlled condition whereas the lowest value 57.74 cm, 61.49 cm and 64.89 cm, respectively was observed with S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The maximum number of leaves $plant^{-1}$ (12.97), tillers $plant^{-1}$ (2.99), effective tillers $plant^{-1}$ (2.55), fresh weight $plant^{-1}$ (11.60 g), dry weight $plant^{-1}$ (4.38 g) and 1000 grain weight (51.08 g) were recorded from S_0 or control treatment whereas minimum number of leaves $plant^{-1}$ (9.89), tillers $plant^{-1}$ (2.02), effective tillers $plant^{-1}$ (1.54), fresh weight $plant^{-1}$ (8.85 g), dry weight $plant^{-1}$ (3.22 g) and 1000 grain weight (26.70 g) were observed from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. The SPAD value was not statistically affected by different levels of salinity. But numerically the maximum SPAD value was recorded from no levels of salt (S_0) with minimum from S_2 (6.0 g NaCl kg^{-1} of soil). The highest grain weight $spike^{-1}$ (1.74 g), number of spikelet spike^{-1} (16.08), number of grains spike^{-1} (33.68), membrane stability (85.81 %), grain yield (1.54 t ha^{-1}), straw yield (1.34 t ha^{-1}), biological yield (2.88 t ha^{-1}) and mitigation (101.3 %) were found from S_0 treatment or control condition while the lowest grain weight spike^{-1} (0.49 g), number of spikelet spike^{-1} (7.92), number of grains spike^{-1} (11.19), membrane stability (34.10 %), grain yield (0.29 t ha^{-1}), straw yield (0.46 t ha^{-1}), biological yield (0.75 t ha^{-1}) and mitigation (18.86 %) were recorded from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. S_1 treatment gave the highest (53.69 %) harvest index whereas S_3 gave the lowest (38.30 %) harvest index.

Plant height showed significant difference in response of foliar application of salicylic acid. The tallest plant height 64.94 cm, 71.23cm and 74.71 cm at 45, 60 DAS and harvest, respectively was produced with the A_2 or 0.4 mM salicylic acid and the shortest plant height 61.50 cm, 67.64 cm and 71.10 cm at 45, 60 DAS and harvest, respectively was produced with the A_0 (without salicylic acid). The maximum number of leaves plant^{-1} (11.86), tillers plant^{-1} (2.72), effective tillers plant^{-1} (2.24), fresh weight plant^{-1} (10.59 g), dry weight plant^{-1} (3.90 g) and 1000 grain weight (44.16 g) were recorded from A_2 treatment or 0.4 mM SA whereas minimum number of leaves plant^{-1} (10.44), tillers plant^{-1} (2.25), effective tillers plant^{-1} (1.88), fresh weight plant^{-1} (9.88 g), dry weight plant^{-1} (3.53 g) and 1000 grain weight (41.23 g) were observed from A_0 treatment. The SPAD value was not statistically influenced by the application of salicylic acid. But numerically the highest SPAD value (36.32 SPAD units) was observed from A_2 whereas the lowest SPAD value (35.33 SPAD units) was observed from A_0. The highest grain weight spike^{-1} (1.39 g), number of spikelet spike^{-1} (13.38), number of grains spike^{-1} (27.61), membrane stability (61.31 %), grain yield (1.08 t ha^{-1}), straw yield (0.97 t ha^{-1}), biological yield (2.05 t ha^{-1}), harvest index (50.39 %) and mitigation (71.09 %) were found from A_2 treatment or 0.4 mM SA while the lowest grain weight spike^{-1} (1.33 g), number of spikelet spike^{-1} (11.69), number of grains spike^{-1} (26.53), membrane stability (58.87 %), grain yield (0.99 t ha^{-1}), straw yield (0.93 t ha^{-1}), biological yield (1.92 t ha^{-1}), harvest index (49.14 %) and mitigation (65.58 %) were recorded from A_0 treatment.

The combinations of salinity and salicylic acid levels had significant effect on almost all parameters. The tallest plant height 68.64 cm, 75.89 cm and 79.41cm at 45, 60 DAS and harvest, respectively was found in S_0A_2 treatment combination and the shortest plant height 56.58 cm.

60.56 cm and 64.00 cm at 45, 60 DAS and harvest, respectively was produced with the S_3A_0. The maximum number of leaves plant^{-1} (13.38), tillers plant^{-1} (3.06), effective tillers plant^{-1} (2.70), fresh weight plant^{-1} (12.15 g), dry weight plant^{-1} (4.60 g) and 1000 grain weight (52.60 g) were recorded from S_0A_2 treatment whereas minimum number of leaves plant^{-1} (9.27), tillers plant^{-1} (1.94), effective tillers plant^{-1} (1.41), fresh weight plant^{-1} (8.64 g), dry weight plant^{-1} (3.14 g) and 1000 grain weight (25.21 g) were observed from S_3A_0 treatment. The SPAD value content was not statistically influenced by the different levels salinity and salicylic acid. But numerically the highest SPAD value 37.49 was observed from S_0A_2 whereas the lowest SPAD value 35.03 was observed from S_3A_0. The highest grain weight spike^{-1} (1.75 g), number of spikelet spike^{-1} (16.50), number of grains spike^{-1} (33.91), membrane stability (86.62 %), grain yield (1.55 t ha^{-1}), straw yield (1.35 t ha^{-1}), biological yield (2.91 t ha^{-1}) and mitigation (102.3 %) were found from S_0A_2 treatment while the lowest grain weight spike^{-1} (1.33 g), number of spikelet spike^{-1} (11.69), number of grains spike^{-1} (26.53), membrane stability (58.87 %), grain yield (0.26 t ha^{-1}), straw yield (0.44 t ha^{-1}), biological yield (0.70 t ha^{-1}) and mitigation (65.58 %) were recorded from S_3A_0 treatment. The maximum (54.89 %) harvest index was observed from S_1A_2 while the lowest harvest index (36.86 %) was recorded from S_3A_0 treatment. Considering the above mentioned results, it may be concluded that, the yield of wheat was gradually decreased by the increase of salinity levels. Among the salicylic acid levels, almost 0.4 mM SA showed the highest result in growth, physiology and yield parameters. Morphological parameters, grain yield and yield contributing parameters of wheat are consistent with salinity and salicylic acid application. Therefore, the present experimental results suggest that the combined effect of without salt (control) and 0.4 mM SA would be beneficial to increase the yield of wheat variety BARI Gom-25.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for analogy the accuracy of the experiment.
2. It needs to conduct more experiments with salinity and salicylic acid levels whether can regulate the morphophygiology, yield and seed quality of wheat BARI Gom-25.
3. It needs to conduct related experiment with other varieties of wheat.

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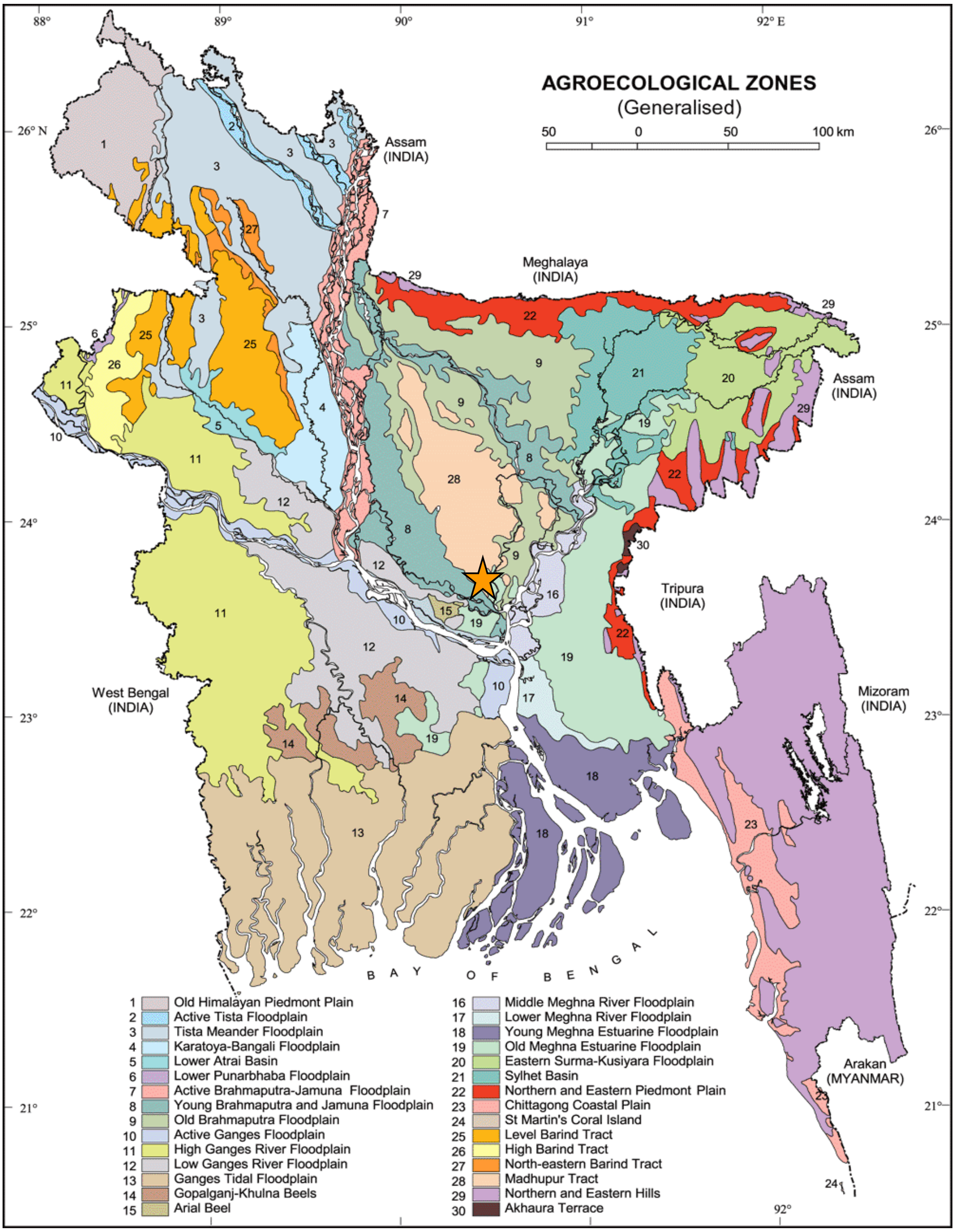
APPENDICES

Appendix I: Physical and chemical composition of soil sample

Characteristics	Value
% Sand	20.84
% Silt	57.46
% Clay	21.7
Textural class	Silt loam
pH	6.9
Organic matter (%)	0.86
Available K (ppm)	25
Available Na (ppm)	70

Appendix II: Experimental location on the map of agro-ecological zones of Bangladesh



Appendix III: Analysis of variance of the data on plant height of wheat under different salinity and salicylic acid levels

Sources of variation	Degrees of freedom	Mean square of plant height (cm) at		
		45 DAS	60 DAS	harvest
Replication	3	42.887	46.248	49.295
Factor A	3	197.872**	368.712*	374.382*
Factor B	2	47.683**	51.819**	52.166**
Ax B	6	2.526**	3.290*	3.571*
Error	33	8.507	10.855	12.306

*significance at 5% level of probability

**significance at 1% level of probability

Appendix IV: Analysis of variance of the data on number of leaves plant^{-1}, number of tillers plant^{-1}, number of effective tillers plant^{-1}, leaf chlorophyll content and Fresh weight plant^{-1} of wheat under different salinity and salicylic acid levels

Source of variation	Degrees of freedom	Mean square of				
		Number of leaves plant^{-1}	Number of tillers plant^{-1}	Number of effective tillers plant^{-1}	SPAD value	Fresh weight plant^{-1} (g)
Replication	3	21.987	0.262	0.740	7.345	17.011
Factor A	3	22.188**	1.965**	2.341**	8.911^{NS}	16.686**
Factor B	2	8.011**	0.906**	0.503**	4.376^{NS}	2.024**
Ax B	6	0.266**	0.164*	0.039 **	0.175^{NS}	0.179*
Error	33	0.500	0.055	0.056	1.444	0.498

*significance at 5% level of probability
**significance at 1% level of probability
NS-not significant

Appendix V. Analysis of variance of the data for crop growth characters, yield and other crop characters of wheat under different salinity and salicylic acid levels

Sources of Variation	Degrees of freedom	Mean square values											
		Dry weight plant^{-1} (g)	Chaff weight spike^{-1} (g)	1000 grains weight (g)	Grain weight spike^{-1} (g)	Number of spikelet spike^{-1}	Number of grains spike^{-1}	Mitigation (%)	Membrane stability (%)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	3	4.771	0.001	3.438	0.040	7.861	1.934	35.409	33.644	0.007	0.014	0.040	0.594
Factor A (Salinity)	3	2.767**	0.024**	1442.193*	4.137*	142.306**	1365.702**	14681.583**	5889.454**	3.405*	1.604**	9.657**	697.870*
Factor B (Salicylic acid)	2	0.777**	0.002^{NS}	32.979**	0.013**	11.646**	4.725**	127.539**	25.297**	0.028**	0.007**	0.064**	6.272**
A × B	6	0.095*	0.003*	0.576**	0.001**	1.118*	0.257*	26.038**	2.454*	0.006**	0.001**	0.011*	1.734**
Error	33	0.363	0.006	3.110	0.014	0.407	1.970	0.416	7.567	0.002	0.001	0.005	0.392

* Significant at 5% level
**Significant at 1% level
NS – Not Significant

Pictorial view of experimental treatment

Pictorial view of experimental treatment