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REGULAR ARTICLE

SALT STRESS MITIGATION BY SALICYLIC ACID IN WHEAT FOR FOOD SECURITY IN COASTAL AREA OF BANGLADESH

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ABSTRACT

Salt stress has a large impact on controlling the plant growth and development. The present study was conducted 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.* S0 = without salt (control), S1 = 2.8 g NaCl kg^{-1} soil ≈ 3-4 dSm^{-1}, S2 = 6.0 g NaCl kg^{-1} soil ≈ 7-8 dSm^{-1}, S3 = 9.0 g NaCl kg^{-1} soil ≈ 11-12 dSm^{-1} and three different levels of salicylic acid (SA) *viz.* A_0 = 0 mmol, A_1= 0.2 mmol and A_2 = 0.4 mmol. It was done by using two factors Randomized Complete Block Design (RCBD) with four replications. The total treatment combinations were 12 (4x3). Results of the experiment showed a significant dissimilarity among the treatments in respect of the major parameters. Yield of wheat were exaggerated by different levels of salinity. The higher levels of salinity showed greater reduction of yield. The highest grain yields (1.55 tha^{-1}) were recorded at S_0A_2 (Without Salt+0.4 mmol salicylic acid) treatment combination which did not show any difference with S_0A_0 (Without Salt+Without SA) and S_0A_1 (Without Salt+0.2 mmol SA). But the grain yield was gradually decreased with the increasing level of salinity. The application of salicylic acid increased the grain yield differently according to the levels of salinity. The minimum grain yields were found 1.14 t ha^{-1}, 1.07 tha^{-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 mmol) from 1.14 to 1.32 tha^{-1}, 1.07 to 1.14 tha^{-1} and 0.26 to 0.31 tha^{-1} at 3-4 dSm^{-1}, 7-8 dSm^{-1} and 11-12 dSm^{-1} NaCl respectively. These results suggest that salicylic acid can alleviate the detrimental impacts of salinity and increase the grain yield of wheat.

Keywords: Salicylic acid, Salt stress, Wheat, Food security, Salinity, Coastal area

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a prime cereal crop at global level as well as second in Bangladesh according to cultivation and production [1]. One third people of the world uses it as a staple food [2]. In 2013-2014, wheat cultivation area was about 1061602 and the total production was 1302998 M. tons and average yield was1233 kg $acre^{-1}$ in Bangladesh [3]. Various environmental stresses such as drought, cold, salinity causes heavy losses in agricultural production due to disruption in physiological and biochemical processes in plant [4-6]. Salinity is major abiotic stressors which hinder crop production. It creates and adversely impacts the socio-economic condition of many developing countries including Bangladesh.

Salt stress is a major problem of the coastal areas of Bangladesh. The system of land use in saline prone areas is not as usual to plain land in respect of crop production [7,8]. Most of the high yielding salt sensitive crop might not be suitable for cultivation in the existing salinity condition [9]. The coastal area covers 13 districts among 64 districts and about 20% of the total areas of Bangladesh and salinity affects 53% of the coastal dwellers [10, 11]. About 2.85 million hectares of the coastal area are affected by salinity of which about 1.2 million hectares of arable land [12]. In terms of the degree of salinity about 203000 hectares, 492000 hectares, 461000 hectares and 492000 hectares are affected very slightly, slightly, moderately, and strongly respectively [13]. Drinking water salinity is another problem which regularly faced about 20 million people coastal dwellers [14]. The coastal people are also affected by water and soil salinity [15]. As a result, people of coastal areas face food insecurity due to low vegetative growth of crop, wilting of crop, low yield, no resistant varieties etc in the form of low availability of food, low access to food, low utilization and no stability of food [16]. The study was intended to solve the salinity problem by salicylic acid in wheat. The coastal dwellers are usually cultivated wheat crops more than other areas, that is why

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wheat crop was purposively selected for this study.

Salinity reduces the growth of wheat plant by reducing the plants ability to absorb water from soil [17]. 10 and 15 dSm^{-1} electrolyte leakages increase due to increasing proline and sugar under salinity condition [18, 19]. It has been reported that wheat's growth and yield will decrease due to increasing salinity [20, 21]. Seedling growth is also hampered due to salinity through changing phytohormone levels [22, 21]. Furthermore, photosynthetic rate, transpiration rate and stomatal activity of wheat reduce due to salt stress which also increases the activity of peroxidase and superoxide dismutase [23]. The height, fertile tillers and shoots dry weight of wheat is largely reducing due to increasing salinity level [24, 25] which also decreases the vegetative growth, biomass and yield through hampering physiological processes [26, 27]. It also encourages respiration of wheat seedlings by consuming carbohydrates [28, 27]. Harris *et al.* [29] reported that 15 mmol salt concentration was able to reduce transpiration rate in seedlings of wheat [29]. Same results found by Perveen *et al.* [30] who mentioned that it also reduces net CO_2 assimilation rate, stomatal conductance and transpiration rate in wheat. Metabolic and physiological activities of plant are greatly influenced by salicylic acid (SA) as a growth regulator [31]. The SA also helps to increase the defense mechanism in plants for alleviate salinity [32, 33, 34]. 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. Considering the fact described above, the present work was undertaken to achieve the objectives (i) To investigate the independent effects of salinity and salicylic acid on changes of yield of wheat, (ii) To investigate the interaction effects of salinity and salicylic acid on changes of yield of wheat, (iii) To find out the best combination between different levels of salinity and salicylic acid on alleviation of salt stress with salicylic acid (SA) of wheat.

MATERIALS AND METHODS

Experimental site and sampling procedure

This study was conducted in the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from November 2014 to March 2015. 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. The soil sample is collected from Modhupur Tract [5] under AEZ No. 28. The characteristics of the sample were analyzed in the Laboratory of Soil Science Department, SAU, Dhaka and details of soil characteristics are as follows.

The study area is a subtropical monsoon climatic zone, which is frequently experienced with heavy rainfall during April to September and light rainfall during rest of the year. Plenty of sunshine and moderately low temperature prevail during October to March (Rabi season), which are suitable for growing of wheat in Bangladesh. 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 d after sowing. The two factorial experiments were 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 mmol SA

ii. A_1 = 0.2 mmol SA

iii. A_2 = 0.4 mmol SA

Total 12 treatment combinations were as follows:

S_0A_0: Without Salt+Without Salicylic Acid
S_0A_1: Without Salt+0.2 mmol Salicylic Acid
S_0A_2: Without Salt+0.4 mmol 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 mmol Salicylic Acid
S_1A_2: 2.8 g NaCl kg^{-1} soil+0.4 mmol 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 mmol Salicylic Acid
S_2A_2: 6.0 g NaCl kg^{-1} soil+0.4 mmol 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 mmol Salicylic Acid
S_3A_2: 9.0 g NaCl kg^{-1} soil+0.4 mmol Salicylic Acid

Design of the experiment

The experiment was done by using two factors Randomized Complete Block Design (RCBD) with four replications 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. A net house was used for the experiment which was made by bamboo with net and pots.

Table 1: 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

Source: Author, 2014

Application of the treatments

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 30thNovember 2014. 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 mmol and 0.4 mmol 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. Seeds were sown on 30th November, 2014. Twelve (12) seeds were sown in each pot. Maturity of crop was determined when 90% of the spike became golden yellow in color. Three plants per pot were preselected randomly. Different growth and yield attributes data were collected. The data were recorded following each pot in harvesting, bundling, and tagging. For maintaining 12% moisture content, the grains were cleaned and sun dried.

Recording of data

The data of yield contributing and yield characters were recorded during the experimentation like number of grains spike^{-1}, number of spikelet spike^{-1}, grain weight spike^{-1} (g), 1000 grain weight (g), grain yield (t ha^{-1}), straw yield (t ha^{-1}), biological yield (t ha^{-1}), harvest Index (%) and mitigation (%). The number of grains spike^{-1} was counted from 3 spikes and number of grains spike^{-1} was measured by the following formula.

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

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

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

Statistical analysis

MSTAT-C computer package program was used for this study. Collected data were categorized, coded and analyzed statistically on the basis of various parameters like analysis of variance (ANOVA) technique. 5% level of significance level was used to measure the mean differences [5].

RESULTS AND DISCUSSION

The results obtained with different levels of salinity (S) and salicylic acid (SA) and their combinations are presented and discussed.

Number of spikelet spike^{-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. 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 reduced with increasing the salinity level. Qiu *et al.* [35] mentioned that about 37% grain yield might loss per plant due to high salinity by reducing spike length and shrinking grain.

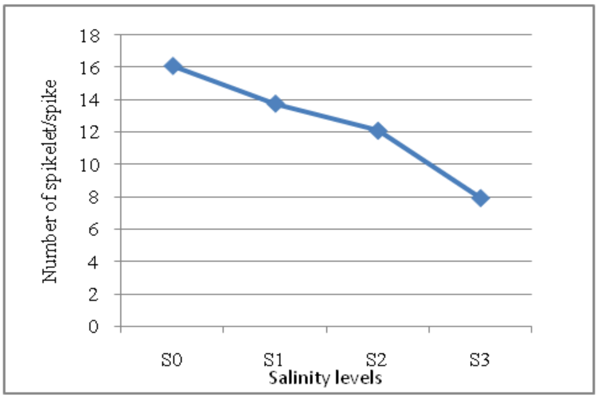

Fig. 1: Effect of different levels of salinity on number of spikelet spike^{-1}of wheat ($LSD_{0.05}$ = 0.530), Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Effect of salicylic acid

Application of salicylic acid had significant variation on the number of spikelet spike^{-1} of wheat. The maximum number of spikelet spike^{-1} 13.38 was observed from A_2 or 0.4 mmol SA whereas the minimum number of spikelet spike^{-1} 11.69 was seen from A_0. The number of spikelet spike^{-1} of wheat increased with increasing the application of salicylic acid. Aldesuquy *et al.* [36] reported that SA might increase spikelets number directly or indirectly.

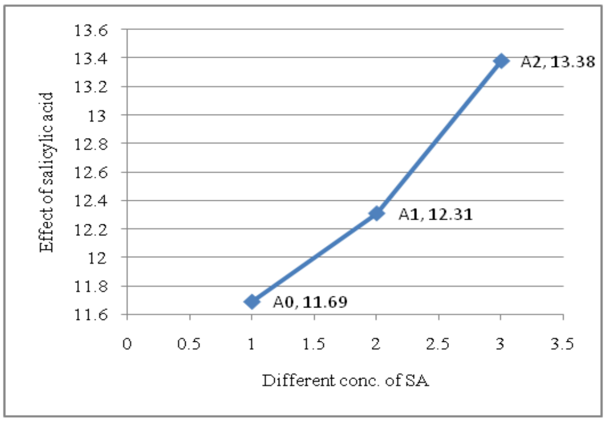

Fig. 2: Effect of different concentration of salicylic acid on number of spikelet spike^{-1}of wheat ($LSD_{0.05}$ = 0.459), Note: A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

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. 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 mmol) increased the yield of wheat.

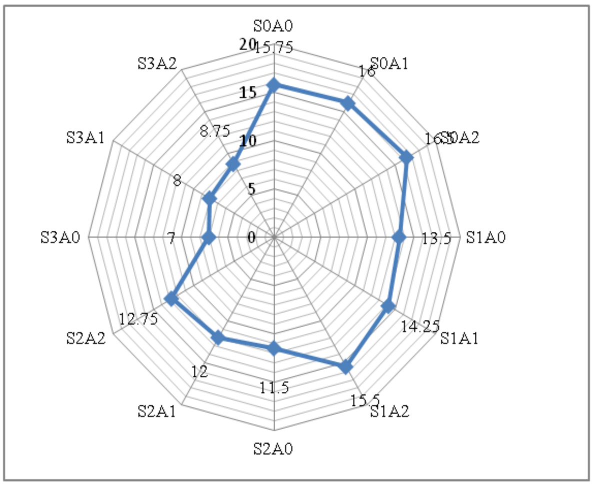

Fig. 3: Combined effect of different levels of salinity and salicylic acid on number of spikelet spike^{-1}of wheat ($LSD_{0.05}$ = 0.918), Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil, A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Number of grains spike

Effect of salinity

The maximum number of grains spike^{-1} 33.68 was seen at 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. El-Hendawy *et al.* [37] found that grain number of wheat was decreased with increasing salinity levels.

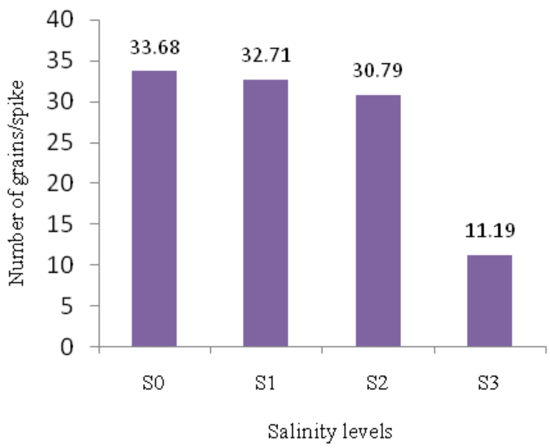

Fig. 4: Effect of different levels of salinity on number of grains spike^{-1}of wheat ($LSD_{0.05}$ = 0.091), Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

Effect of salicylic acid

The number of grains spike^{-1}was meaningfully influenced by different concentration of salicylic acid. The maximum number of grains spike^{-1} 27.61 was observed from A_2 or 0.4 mmol SA on the other hand, the minimum grains spike^{-1} 26.53 was detected from A_0. The increasing the application of salicylic acid increases number of grains spike^{-1}.

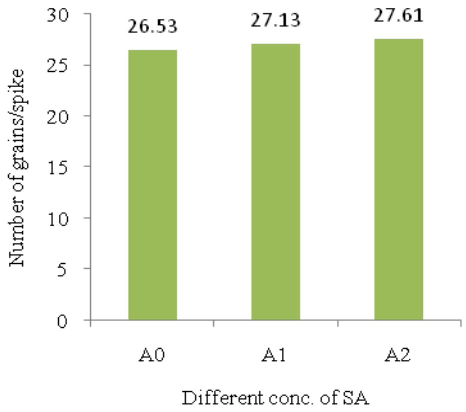

Fig. 5: Effect of different concentration of salicylic acid on number of grains spike^{-1}of wheat ($LSD_{0.05}$ = 0.079), Note: A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Interaction effect of salinity and salicylic acid

A significant variation on the number of grains spike-1 of wheat was found by using combined salinity and salicylic acid. The Maximum grains spike-1 33.91 was observed from S_0A_2 whereas the minimum grains spike-1 10.39 was recorded from S_3A_0 treatment. The application of salicylic acid (0.04 mmol) increased the yield of wheat.

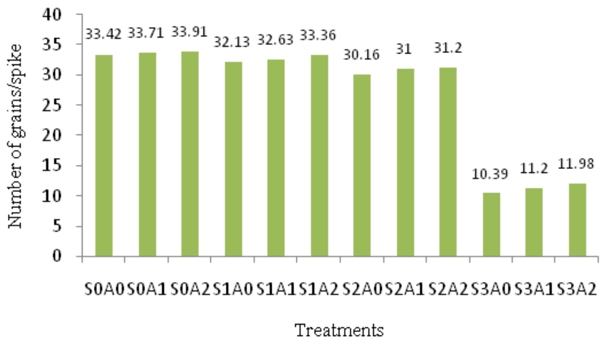

Fig. 6: Combined effect of different levels of salinity and salicylic acid on number of grains spike^{-1}of wheat ($LSD_{0.05}$ = 0.158); Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil, A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Grain weight spike^{-1} (g)

Effect of salinity

A noteworthy difference was found at different levels of salinity for grain weight spike^{-1} of wheat. The highest grain weight spike^{-1} 1.74 g was found 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.

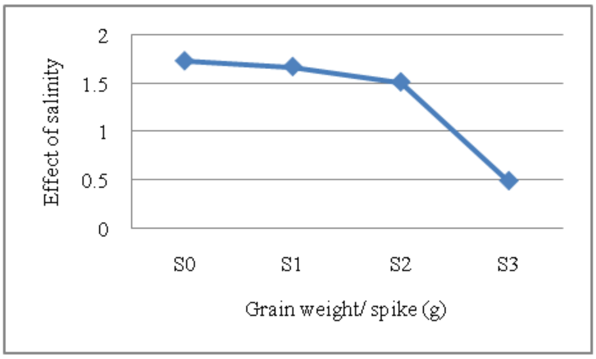

Fig. 7: Effect of different levels of salinity on grain weight spike^{-1} of wheat (LSD$_{0.05}$ = 0.037), S$_0$ = without salt (control), S$_1$ = 2.8 g NaCl kg^{-1} of soil, S$_2$ = 6.0 g NaCl kg^{-1} of soil, S$_3$ = 9.0 g NaCl kg^{-1} of soil

Effect of salicylic acid

Different concentration of salicylic acid had significant variation on grain weight spike^{-1} (g) of wheat. The maximum grain weight spike^{-1} 1.39 g was observed from A$_2$ or 0.4 mmol 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. Zhou *et al.* [38] who mentioned that maize stem inserted with SA shaped 9% more grain weight.

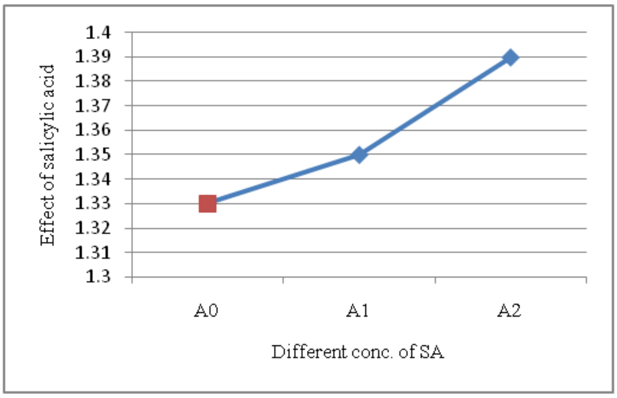

Fig. 8: Effect of different concentration of salicylic acid levels on grain weight spike^{-1} of wheat (LSD$_{0.05}$ = 0.032); Note: A$_0$ = No salicylic acid, A$_1$ = 0.2 mmol SA, A$_2$ = 0.4 mmol SA

Interaction effect of salinity and salicylic acid

Interaction of salinity and salicylic acid showed significant variation on grain weight spike^{-1} (g) of wheat. The highest grain weight spike^{-1} 1.75 g was observed from S$_0$A$_2$ which was statistically similar S$_0$A$_0$ (1.73 g) and S$_0$A$_1$ (1.75 g) while the lowest grain weight spike^{-1} 0.47 g was found from S$_3$A$_0$ treatment which was similar S$_3$A$_1$ (0.49 g) and S$_3$A$_2$ (0.51 g).

Weight of 1000 grains (g)

Effect of salinity

1000 grains weight reduced with increasing salinity level in wheat. 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 found from S$_2$. The similar results found by El-Hendawy et al. [37] and Gain et al. [38].

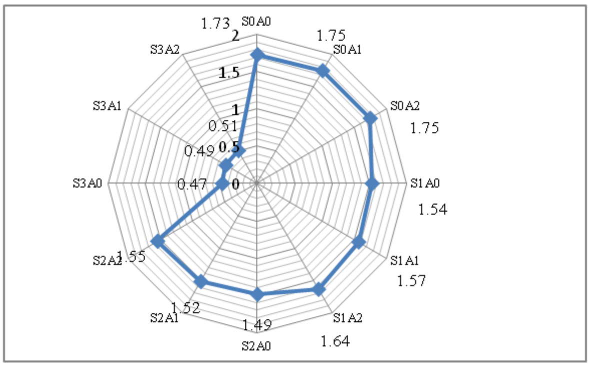

Fig. 9: Combined effect of different levels of salinity and salicylic acid on grain weight spike^{-1} of wheat (LSD$_{0.05}$ = 0.064); Note; S$_0$ = without salt (control), S$_1$ = 2.8 g NaCl kg^{-1} of soil, S$_2$ = 6.0 g, NaCl kg^{-1} of soil, S$_3$ = 9.0 g NaCl kg^{-1} of soil, A$_0$ = No salicylic acid, A$_1$ = 0.2 mmol SA, A$_2$ = 0.4 mmol SA

Effect of salicylic acid

Various salicylic acid level had significant impact on 1000 grains weight of wheat. The maximum was weight 44.16 g which was observed from A$_2$ or 0.4 mmol SA while 41.23 g was found in A$_0$. The 1000 grains weight of wheat increased with increasing the application of salicylic acid.

Interaction effect of salinity and salicylic acid

The 1000 grains weight (g) of wheat showed a mentionable difference due to the combined effect of salinity and salicylic acid. The highest 1000 grains weight was 52.60 g which was found in S$_0$A$_2$ while the lowest 1000 grains weight was 25.21 g which was found in S$_3$A$_0$ treatment. Aldesuquy et al. [36] mentioned that the application of salicylic acid (0.05 M) increased the yield of two wheat cultivars.

Grain yield (t ha^{-1})

Effect of salinity

The highest grain yield was 1.54 t ha^{-1} which was found in S$_0$ or control whereas the lowest was 0.29 t ha^{-1} value in S$_3$ salinity level or addition of NaCl 9.0 g kg^{-1} soil. The gradual decrease of yield was found with increasing levels of salinity.

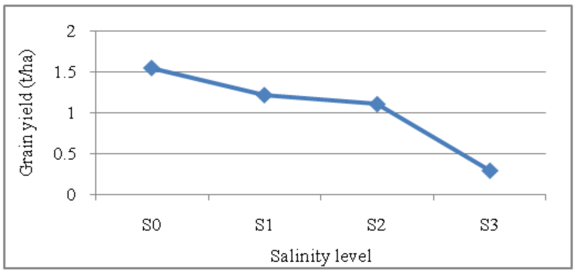

Fig. 10: Effect of different levels of salinity on grain yield of wheat (LSD$_{0.05}$ = 0.037), Note: S$_0$ = without salt (control), S$_1$ = 2.8 g NaCl kg^{-1} of soil, S$_2$ = 6.0 g NaCl kg^{-1} of soil, S$_3$ = 9.0 g NaCl kg^{-1} of soil

Effect of salicylic acid

In this study the grain yield was converted into hectare[-1]and has been expressed in metric tons. Various salicylic acid level had significant result on the grain yield of wheat ton hectare^{-1}. The highest grain yield was 1.08 t ha^{-1} which was observed from A_2 or 0.4 mmol SA whereas the lowest grain yield was 0.99 t ha^{-1} which was observed from A_0. The grain yield of wheat was increased with increasing the application of salicylic acid.

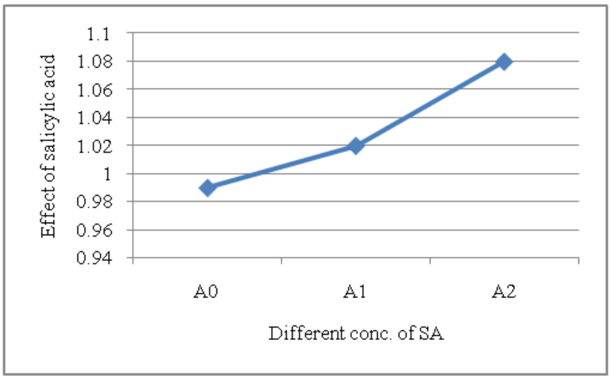

Fig. 11: Effect of different concentration of salicylic acid on grain yield of wheat ($LSD_{0.05}$ = 0.032), Note: A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Interaction effect of salinity and salicylic acid

There was a significant combined effect of different levels of salinity and salicylic acid concentrations and showed noteworthy difference on the grain yield of wheat. The maximumgrain 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 found from S_3A_0 treatment which was statistically similar with S_3A_1 (0.29 t ha^{-1}).

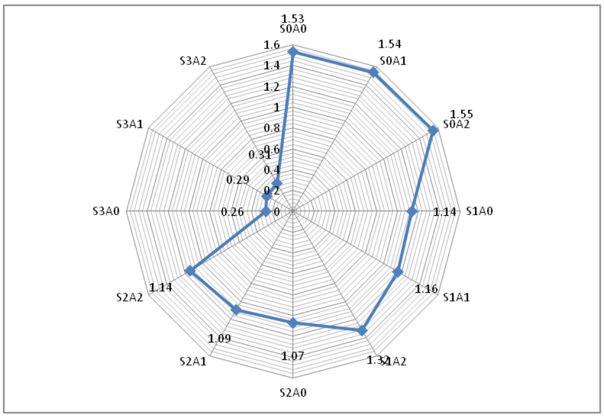

Fig. 12: Combined effect of different levels of salinity and salicylic acid on grain yield of wheat ($LSD_{0.05}$ = 0.064); Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil, A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Straw yield (t ha^{-1})

Effect of salinity

Significant difference was documented for straw yield (t ha^{-1}) of wheat due to the different salinity levels. The maximum straw yield 1.34 t ha^{-1} was gotten 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 exposed the gradual decrease of straw yield with the increased levels of salinity.

Table 2: 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

Table 3: 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 mmol SA, A_2 = 0.4 mmol SA, **significant at 1% level of probability

Table 4: 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 mmol SA, A_2 = 0.4 mmol SA ** significant at 1% level of probability, * significant at 5% level of probability.

Effect of salicylic acid

Various salicylic acid level had substantial result on the straw yield of wheat. The highest straw yield was 0.97 t ha^{-1} which was observed from A_2 or 0.4 mmol SA whereas the lowest 0.93 t ha^{-1} was observed from A_0 which was similar with. A_1 (0.95 t ha^{-1}).

Interaction effect of salinity and salicylic acid

There was a significant combined effect of different levels of salinity and salicylic acid concentrations and found substantial difference on the straw yield of wheat. The maximumstraw yield 1.35 t ha^{-1} was observed from S_0A_2 which was 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 found from S_3A_0 treatment was similar with S_3A_1 (0.46 t ha^{-1}) and S_3A_2 (0.48 t ha^{-1}).

Biological yield (t ha^{-1})

Effect of salinity

Biological yield was significantly affected by various salinity levels. 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 gradual decrease of biological yield was found with increasing levels of salinity. Kumar *et al.* [39] stated that biological yield and harvest index were significantly decreased by salinity.

Influence of salicylic acid

Biological yield was mentionably affected by the various salicylic acid level. The highest biological yield 2.05 t ha^{-1} was found from A_2 or 0.4 mmol 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 [40].

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. The maximum2.91 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.

Harvest index (%)

Effect of salinity

Harvest index (%) was affected by various levels of salinity. The highest harvest index 53.69% was found in S_1 which was statistically similar with S_0 (53.50%) and S_2 (53.44%) while the lowest 38.30% value from S_3 salinity level or addition of NaCl 9.0 g kg^{-1} soil. Hossain [41] found that harvest index was decreased with increasing the salinity level in rice. Similar result was also reported by Hossain *et al.* [42] and Rana [43] in rice.

Effect of salicylic acid

Harvest index (%) was mentionably influenced by the various concentrations of salicylic acid of wheat. The highest harvest index 50.39% was found in A_2 or 0.4 mmol 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.

Interaction effect of salinity and salicylic acid

Interaction effect between various levels of salinity and salicylic acid concentrations was significant in respect of harvest index of wheat. The maximum54.89% 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 [32,33].

Mitigation (%)

Effect of salinity

Mitigation (%) was meaningfully influenced by various levels of salinity. The maximum salt alleviation percentage 101.3 was found in 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.

Effect of salicylic acid

The percentage of mitigationwas significantly affected by different concentration of salicylic acid. The highest salt alleviation percentage 71.09 was observed from A_2 or 0.4

mmol SA whereas the lowest salt alleviation percentage 65.58 was observed from A_0 or control.

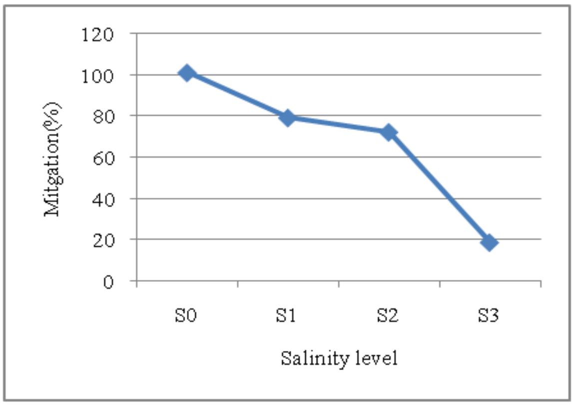

Fig. 13: Effect of different levels of salinity on mitigation (%) of wheat ($LSD_{0.05}$ = 0.298), Note: S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil

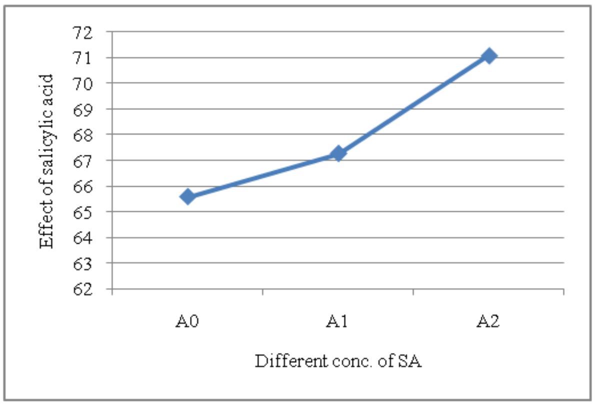

Fig. 14: Effect of different concentration of salicylic acid on mitigation (%) of wheat ($LSD_{0.05}$ = 0.260), Note: A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Interaction effect of salinity and salicylic acid

Combined effect of salinity and salicylic acid showed significant variation on the mitigationpercentage of wheat. The highest salt alleviation percentage86.84 was observed from S_1A_2 while the lowest salt alleviation percentage 16.94 was recorded from S_3A_0 treatment. The interaction effect of various salinity levels and salicylic acid can successfully alleviate the salt stress in wheat.

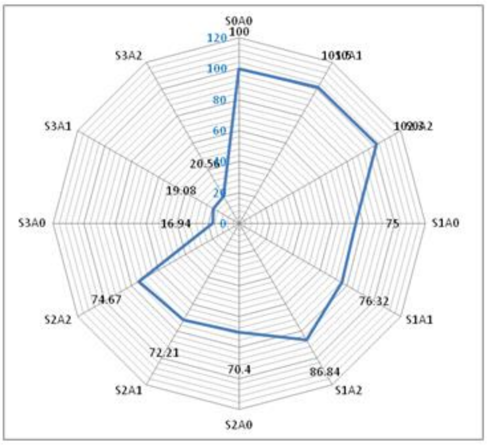

Fig. 15: Combined effect of different levels of salinity and salicylic acid on mitigation (%) of wheat ($LSD_{0.05}$ = 0.517), S_0 = without salt (control), S_1 = 2.8 g NaCl kg^{-1} of soil, S_2 = 6.0 g NaCl kg^{-1} of soil, S_3 = 9.0 g NaCl kg^{-1} of soil A_0 = No salicylic acid, A_1 = 0.2 mmol SA, A_2 = 0.4 mmol SA

Relationship among various factors with yield of wheat

The relationship among salinity, salicylic acid and combine effect of salinity and salicylic acid exhibited different significant variation (Table 5). There was a positive significant relationship among the yield contributing characters with various levels of salinity at 1% and 5% level of significance. The mentionable responses of salinity showed on three yield contributing characters like 1000 grains weight, numbers of grain per spikelet and mitigation. The salicylic acid had a positive significant relationship with all yield associated traits. The mentionable responses of salicylic acid were on 1000 grains weight and mitigation. Besides, there was a positive significant relationship among all the yield contributing traits with various levels of combination of salinity and salicylic acid. It is mentionable that all the relationships were positively related.

Table 5: Analysis of variance of the data for yield and other crop characters of wheat under different salinity and salicylic acid levels

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

Note: * Significant at 5% level; **Significant at 1% level; NS–Not Significant

CONCLUSION

The present study explored the impact of salicylic acid on the alleviation of salt stress. It also discussed various aspects of soil salinity impact on wheat yield and explored that salicylic acid was the potential growth stimulator of wheat even in salinity prone areas of Bangladesh by alleviating salt stress. The study revealed that the yield of wheat was gradually decreased by the increase of salinity levels. It was also explored that salicylic acid could alleviate the detrimental effect of salt stress of wheat. Among the salicylic acid levels, almost 0.4 mmol SA showed the highest result in growth, physiology and yield parameters. Morphological parameters, grain yield and yield contributing parameters of wheat were consistent with salinity and salicylic acid application. It suggests that the combined effect of without salt (control) and 0.4 mmol SA would be beneficial to increase the yield of wheat variety BARI Gom-25.

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