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Drought stress response of rice yield (*Oryza sativa* L.) and role of exogenous salicylic acid

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Abstract

The scarcity of water is a severe environmental constraint to plant productivity. The exogenous application of salicylic acid (SA) has been found very effective in reducing the adverse effects of drought stress. A pot experiment was conducted to determine the drought mitigating effect of Salicylic acid on rice based on Randomized Complete Block Design (RCBD) with three replications during the 2017-2018 growing season at Dhaka, Bangladesh. The treatments of salicylic acid including 0, 250, 500, 750 and 1000 μMm^{-2} concentrations and drought stress consisted of control, moderate and severe stresses. Significantly higher number of panicle $hill^{-1}$, number of filled grain $hill^{-1}$, and number of unfilled grain $hill^{-1}$, 1000 grains weight, grain yield, straw yield and harvest index were found in plants treated with 750 μMm^{-2} SA compared with other treatments and control plants. Results signify the role of SA in regulating the drought response of plants and suggest that SA could be used as a potential protectant, for improving plant growth and productivity under water stress.

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Introduction

Salicylic acid (SA) is an endogenous growth regulator of phenolic nature and also a signaling molecule, which participates in the regulation of physiological processes in plants such as growth, photosynthesis, and other metabolic processes. Several studies support a major role of SA in modulating the plant response to various abiotic stresses.

Salicylic acid (SA), a phenolic compound, is associated with stress tolerance in plants. Salicylic acid is the first plant derivative phenolic compound to induce systemic acquired resistance. Several researchers reported that SA can induce tolerance against abiotic and biotic stress including high and low temperatures, drought, salinity, ultraviolet light, heavy metal toxicity, diseases and pathogens (Hayat and Ahmad, 2007; Hussain *et al.*, 2008). Salicylic acid has positive effects on plant growth and developmental processes (Senaratna *et al.*, 2000). Salicylic acid can modulate the antioxidant defense system thereby decreasing oxidative stress (Shirasu *et al.*, 1997). Photosynthesis, nitrogen metabolism, proline (Pro) metabolism, production of glycine betaine (GB), and plant-water relations in abiotic stress affected plants were regulated by SA (Miura and Tada, 2014). Maity and Bera (2009) in Vigna radiate and Khan *et al.* (2010) in mungbean stated that the affirmative effect of salicylic acid was because of the function of SA is increasing biochemical and physiological processes or enhancing in the activity of N, P, K and Ca in antioxidant enzymes and the content of glutathione. Khandaker *et al.* (2011) found that the application of SA at low concentrations caused an increment in soybean, maize and wheat plant growth but at higher concentrations decreased the growth of tomato, lupine, wheat and maize plants.

Foliar application of phenolic compounds such as salicylic acid, hydrogen peroxide, ethylene and nitric oxide, has huge potential in ameliorating tolerance of drought tension (Zhu, 2002; Wahid *et al.* 2007). The salicylic acid application develops photosynthetic capacity in spring wheat and barley under drought pressure (El-Tayeb, 2005; Arfan *et al.* 2007).

Drought stress is one of the most devastating abiotic stresses adversely affecting the growth and developmental processes of the plant. Exposure of plants to drought stress substantially decreases leaf water potential (WW), relative water contents (RWC) and transpiration rate with the associated increase in leaf temperature (Halder and Burrage, 2003). Drought stress affects the physiological processes, brings biochemical changes, leads to the formation of secondary metabolites, significantly accumulates endogenous reactive oxygen species (ROS) and increases toxins (Hasanuzzaman *et al.*, 2017). Drought stress hampering reproductive development drastically reduces the yield or productivity of plants (Hasanuzzaman *et al.*, 2014). Moreover, exposure of plants to drought quite often leads to the generation of reactive oxygen species (ROS) (El-Tayeb and Ahmed, 2007; Farooq *et al.* 2009). Being highly reactive, ROS can seriously damage plants by lipid peroxidation, protein degradation, DNA fragmentation and ultimately cell death (Foyer and Fletcher, 2001).

Although a number of reports to date have indicated the protective role of SA under environmental stress conditions, the amount of research conducted on the effect of exogenous applications of SA on yield characters of rice under drought stress conditions is limited. Therefore, this experiment was conducted to study the drought stress response of rice yield (*Oryza sativa* L.) and role of exogenous salicylic acid.

Materials and methods

Experimental site

The pot experiment was conducted at the Research Field of Sher-e-Bangla Agricultural University, Dhaka-1207 from November, 2017 to July, 2018. The soil of the experimental pot belongs to the general soil type, shallow red-brown terrace soil with silty clay. Soil pH was 5.6 and has organic carbon 0.45%.

Treatments and experimental design

Rice variety (BRRI dhan28) `was used as the test crop in this experiment. The experiment comprised two factors *viz.* salicylic acid concentrations: control, 250 µMm-2, 500 µMm-2, 750 µMm-2 and 1000 µMm-2 and different drought stresses: control (normal irrigation), severe drought stress (water withheld from Panicle initiation stage to season end) and moderate drought stress (water withheld from flowering stage to season end).

The experiment was laid out in a randomized complete block design (RCBD) with three replications. There were 45 pots containing 24 kg soil in each pot.

Crop husbandry

The seeds were sown in the seedbed @ 70 gm^{-2} to have healthy seedlings. The fertilizers were applied 8 ton cowdung, 215 kg urea, 180 kg TSP and 100 kg MP ha^{-1} as the source of NPK.

The whole amount of cowdung, TSP, MOP and 1/3rd if urea was applied before the final preparation of pots. Intercultural operations were done to ensure the normal growth of the crop. Plant protection measures were followed as and when necessary.

Application of salicylic acid (SA)

In the experiment, the foliar application of the SA solution was applied in three installments. 1st, 2nd and 3rd spray were done at 20, 30 and 40 days after transplanting (DAT), respectively.

Data collection

Plants were selected randomly from each pot. Data on the following parameters were recorded during the period of the experiment such as:- Number of panicle $hill^{-1}$, Number of filled grain $hill^{-1}$, Number of unfilled grain $hill^{-1}$, 1000 grains weight, Grain yield, Straw yield and Harvest index.

Statistical analysis

All the collected data were tabulated and analyzed statistically using analysis of variance technique using a statistical computer software Statistix 10 and subsequently, the least significance difference (LSD at 5%) for comparing the treatment means (Gomezm and Gomez, 1984).

Results and discussion

Panicles $hill^{-1}$

Salicylic acid remarkably influenced the panicle $hill^{-1}$ of rice by a considerable reduction of drought stress. Results indicated that among the different SA concentration, 750 μMm^{-2} SA showed the maximum stress tolerance and gave the highest number of panicle $hill^{-1}$ (Table 1).

Table 1. Effect of salicylic acid on yield and yield contributing character of rice.

Salicylic acid	Panicle $hill^{-1}$ (No.)	Filled grain $panicle^{-1}$ (No.)	Unfilled grain $panicle^{-1}$ (No.)	1000 grains weight (g)	Grain yield (g)	Straw yield (g)	Harvest index (%)
Control	9.00 d	25.33 d	17.00 a	17.13 d	9.32 c	19.32 a	32.45 c
250 μMm^{-2}	11.50 c	31.33 c	14.67 b	18.078 c	9.60 bc	18.76 ab	33.75 bc
500 μMm^{-2}	14.83b	39.33 b	13.00 c	19.19 b	10.05 b	18.30 bc	35.35 b
750 μMm^{-2}	17.22 a	47.26 a	12.61c	19.84 a	11.03 a	17.86 c	38.15 a
1000 μMm^{-2}	12.91c	37.48b	14.28 b	18.33 c	9.82 bc	18.32 a-c	34.77 b
$LSD_{(0.05)}$	1.33	3.19	0.85	0.46	0.56	0.86	1.80
CV (%)	11.13	9.69	6.49	2.73	6.20	5.10	5.68

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

Usharani *et al.* (2014) observed the proportionately increased in a number of panicles $hill^{-1}$ compare to control by the application of salicylic acid.

Drought stress considerably influenced the number of panicle $hill^{-1}$ of rice. Results declare that, among the different level of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) exhibit the lowest number of panicle $hill^{-1}$ (Table 2). Pandy *et al.* (2000) reported that drought tension at different growth stages of maize reduced kernel no/row. Corn has a high sensitivity to drought stress 2 weeks before and after pollination which reduces the number of kernels of the ear.

Table 2. Effect of different level of drought stress on yield and yield contributing character of rice.

Drought stress	Panicle hill^{-1} (No.)	Filled grain panicle^{-1} (No.)	Unfilled grain panicle^{-1} (No.)	1000 grains weight (g)	Grain yield (g)	Straw yield (g)	Harvest index (%)
Control	16.42 a	44.40 a	11.84 c	19.515 a	11.21 a	17.84 b	38.58 a
Severe drought stress	9.48 c	27.70 c	16.74 a	17.537 c	8.89 c	19.15 a	31.63 c
Moderate drought stress	13.38 b	36.35 b	14.34 b	18.499 b	9.78 b	18.56 a	34.49 b
$LSD_{(0.05)}$	1.12	2.68	0.71	0.39	0.47	0.72	1.52
CV (%)	11.13	9.69	6.49	2.73	6.20	5.10	5.68

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

The interaction effect of SA and drought stresses had considerably influenced the number of panicle hill^{-1}. The maximum number of panicle hill^{-1} was reported from 750 µMm^{-2} SA with control stress treatment whereas the minimum from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Number of filled grains panicle^{-1}

Salicylic acid greatly influenced the number of filled grains panicle^{-1} of rice by a considerable reduction of drought stress. Results indicated that among the different SA concentration, 750 µMm^{-2} SA showed the maximum stress tolerance and produce the highest number of filled grains panicle^{-1} (Table 1). Singh *et al.* (2015) and Usharani *et al.* (2014) showed that filled grain panicle^{-1} increased significantly by the application of salicylic acid.

Drought stress significantly influenced the number of filled grains panicle^{-1} of rice. Results revealed that, among the different level of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) demonstrate the lowest number of filled grains panicle^{-1} (Table 2). Decreased filled grain per panicle under lower soil moisture levels might be due to inhibition of translocation of assimilates to the grain due to moisture stress. These results agree with Hossain (2001) who observed that the number of filled grain panicle^{-1} was decreased due to moisture stress. Farooq *et al.* (2009) found that a reduction in grain filling occurs due to a reduction in the assimilate partitioning and activities of sucrose and starch synthesis enzymes.

The interaction effect of SA and drought stresses had notably influenced the number of unfilled grains panicle^{-1}. The highest number of unfilled grains panicle^{-1} was found from 750 µMm^{-2} SA with control stress treatment whereas, the lowest from 0 µMm^{-2} SA with severe stress treatment (Table 3). The results obtained from all other treatment combinations were significantly different compared to the highest and the lowest number of filled grains panicle^{-1}.

Number of unfilled grains panicle^{-1}

Salicylic acid signifies the number of unfilled grains panicle^{-1} of rice by a remarkable reduction of drought stress. Results showed that among the different SA concentration, 750 µMm^{-2} SA demonstrated the highest stress tolerance and produce the lowest number of unfilled grains panicle^{-1} (Table 1).

These results showed that the number of unfilled grains panicle^{-1} was decreased with increasing levels of SA as a foliar application. Mohammed (2011) reported that the number of unfilled grains panicle^{-1} was decreased due to the application of SA.

Drought stress signifies the number of unfilled grains panicle^{-1} of rice. Results demonstrate that, among the different levels of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) showed the maximum number of unfilled grains panicle^{-1} (Table 2).

Increased unfilled grains per panicle under lower soil moisture levels might be due to inactive pollen grains for dryness, incomplete development of pollen tube, insufficient assimilate production and its distribution to grains due to soil moisture stress. The results are in agreement with the findings of Hossain (2001) and Islam *et al.* (1994) who stated that the increased number of unfilled grains panicle^{-1} is due to water stress conditions. The combined effect of SA and drought stresses had notably influenced the number of unfilled grains panicle^{-1}. The lowest number of unfilled grains panicle^{-1} was observed from 750 µMm^{-2} SA with control stress treatment whereas, the highest from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Table 3. Interaction effect of salicylic acid and different level of drought stress on yield and yield contributing character of rice.

Salicylic acid × Drought stress	Panicle hill^{-1} (No.)	Filled grain panicle^{-1} (No.)	Unfilled grain panicle^{-1} (No.)	1000 Grains weight (g)	Grain yield (g)	Straw yield (g)	Harvest index (%)
Control	12.00 fg	30.00 ef	14.00 cd	18.100 ef	10.80 bc	18.86 a-c	36.422 b-e
0 µMm^{-2}×severe	6.00 k	20.00 h	20.00 a	16.20 h	7.65 g	19.96 a	27.72 h
0 µMm^{-2}×moderate	9.00 ij	26.00 fg	17.00 b	17.10 g	9.49 e	19.13 ab	33.21 e-g
250 µMm^{-2}×control	15.00 de	38.00 c	12.00 e-g	19.13 cd	10.75 bc	18.23 b-d	37.02 b-d
250 µMm^{-2}×severe	8.00 jk	24.00 gh	17.00 b	17.06 g	8.41 fg	19.16 ab	30.49 gh
250 µMm^{-2}×moderate	11.50 gh	32.00 de	15.00 c	18.03 f	9.63 de	18.90 a-c	33.74 d-g
500 µMm^{-2}×control	18.00 b	49.00 b	11.00 fg	20.23 ab	11.25 ab	17.46 cd	39.09 ab
500 µMm^{-2}×severe	11.00 g-i	30.00 ef	15.00 c	18.13 ef	9.02 ef	18.86 a-c	32.31fg
500 µMm^{-2}×moderate	15.50 de	39.00 c	13.00 de	19.20 cd	9.86 c-e	18.56 a-c	34.65 c-f
750 µMm^{-2}×control	20.64 a	58.51 a	10.78 g	20.89 a	12.01 a	16.98 d	41.39 a
750 µMm^{-2}×severe	13.29 ef	36.01 cd	14.78 c	18.86 de	10.51 b-d	18.66 a-c	35.99 b-e
750 µMm^{-2}×moderate	17.72 bc	47.26 b	12.28 ef	19.79 bc	10.54 b-d	17.93b-d	37.08 bc
1000 µMm^{-2}×control	16.46 b-d	46.48 b	11.44 e-g	19.22 cd	11.24 ab	17.62 b-d	38.96 ab
1000 µMm^{-2}×severe	9.13 h-j	28.48 e-g	16.94 b	17.42 fg	8.85 ef	19.07 a-c	31.61fg
1000 µMm^{-2}×moderate	13.16 e-g	37.48 cd	14.44 cd	18.37 d-f	9.35 ef	18.27 a-d	33.74 c-g
$LSD_{(0.05)}$	2.11	5.07	1.35	0.73	0.89	1.37	2.87
CV (%)	11.13	9.69	6.49	2.73	6.20	5.10	5.68

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

1000 grains weight

Salicylic acid remarkably influenced the 1000 grains weight of rice by a considerable reduction of drought stress. Results indicated that among the different SA concentration, 750 µMm^{-2} SA showed the maximum stress tolerance and gave the highest 1000 grains weight (Table 1). Ibrahim *et al.* (2014) showed that 1000 grain weight increased significantly by the application of SA.

Drought stress considerably influenced the number of 1000 grains weight of rice. Results declare that, among the different level of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) exhibit the lowest 1000 grains weight (Table 2). Lower soil moisture might decrease the translocation of assimilates to the grain which lowered grain size and increased empty grain. The results are in agreement with the findings of Rahman *et al.* (2002) and Zubaer *et al.* (2007) who observed that water stress reduced grain weight in different varieties of rice.

The interaction effect of SA and drought stresses had considerably influenced 1000 grains weight. The maximum 1000 grains weight was found from 750 µMm^{-2} SA with control stress treatment whereas, the minimum from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Grain yield

Salicylic acid greatly influenced the grains yield of rice by a remarkable reduction of drought stress. Results declare that among the different SA concentration, 750 µMm^{-2} SA showed the greatest stress tolerance and produced the maximal grain yield (Table 1).

Increasing grain yield result may cause due to the increased tiller per hill, increased filled grain per panicle, increased amount of chlorophyll content which helps the plant to produce more food. Ultimately the grain yield increases.

It was further reported by Zamaninejad *et al.* (2013) that the application of salicylic acid (1 mM) on maize plants (*Zea mays* L.) modified the negative effects of water stress on grain yield by increasing grain number spikes^{-1} significantly. Saranraj (2014) and Usharani *et al.* (2014) also showed that the application of SA can increase the grain yield.

Drought stress significantly influenced the grain yield of rice. Results revealed that, among the different level of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) demonstrate the minimal grains yield (Table 2). So, it was observed that grain yield hill^{-1} decreased in decreasing moisture levels. Reduced grain yield under lowered soil moisture levels might be due to inhibition of photosynthesis and less translocation of assimilates towards reproductive parts due to soil moisture stress. This result agrees with Hossain (2001) who observed that grain yield hill^{-1} was decreased with decreasing soil moisture levels.

The combined effect of SA and drought stresses had a great influence on grain yield. The highest grain yield was reported from 750 µMm^{-2} SA with control stress treatment whereas, the lowest from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Straw yield

Salicylic acid remarkably influenced the straw yield. Results indicated that among the different SA concentration, 750 µMm^{-2} SA showed the maximum stress tolerance and gave the minimum straw yield (Table 1). This result is strongly supported by Saranraj (2014) and Usharani *et al.* (2014) who showed that the application of SA had a significant influence on straw yield. Drought stress considerably influenced the straw yield of rice. Results declare that, among the different level of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) exhibit the highest straw yield (Table 2).

The combined effect of SA and drought stresses had a great influenced on straw yield. The lowest straw yield was observed from 750 µMm^{-2} SA with control stress treatment whereas, the highest from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Harvest index

Salicylic acid significantly influenced the harvest index of rice. Results demonstrated that among the different SA concentration, 750 µMm^{-2} SA exhibit the maximum stress tolerance and gave the maximum harvest index (Table 1).

Drought stress considerably influenced the harvest index of rice. Results indicate that, among the different levels of drought stress, severe drought stress (water withheld from Panicle initiation stage to season end) showed the minimum harvest index (Table 2).

This result might be due to the fact that water stress affected the translocation toward the grains. The present results agree with the report of Islam (1999) and Islam *et al.* (1994).The combined effect of SA and drought stresses had a great influence on the harvest index. The highest harvest index was reported from 750 µMm^{-2} SA with control stress treatment whereas, the lowest from 0 µMm^{-2} SA with severe stress treatment (Table 3).

Conclusion

The results of the present investigation suggest that the protective action of SA may be associated with a reduction in transpiration rate and an enhancement of photosynthesis, which together, increased water use efficiency under drought. So, it was concluded that in drought stress, it's better to use salicylic acid @750 µMm^{-2} for modifying the effects of drought on rice yield. However, further experimentation is required for a comprehensive conclusion for a practical purpose.

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