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Cooperative Effect of Salicylic Acid and Boron on the Productivity of Pearl Millet Crop under the Degraded Saline Soils Conditions

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DROUGHT and salinity are the most limiting factors for crop production in arid and semi-arid areas. Moreover, pearl millet cultivation may be an excellent selection in arid and saline lands. Therefore, two field experiments were conducted at the Desert Research Center, Agriculture Experimental Station at Ras Sudr, South Sinai Governorate, Egypt during 2018 and 2019 seasons, to study the effect of seed priming (as seed soaking) using five salicylic acids levels (tap water as a control, 50, 100, 150 and 200 mg/L SA) and fertilizing soil application by five boron rates (without boron, 1.0, 2.0, 3.0 and 4.0 kg boron/fed, as boric acid) on pearl millet yields. The results showed that plant height (cm), panicle length (cm), panicles number/m^2, grain weight/panicle (g), seed index (g) and grain protein content percentage as well as biological, grain and protein yields (kg/fed) were significantly increased by salicylic acid (SA) levels in both seasons. Soaking the grains of pearl millet in 200 mg/L SA treatment was the best practice in both seasons as compared to the other treatments. Regarding the effect of boron (B) treatments, all the abovementioned characters were significantly affected by B treatments in the two studied seasons. Adding 3 kg B/fed gave the highest values of all the studied attributes in both seasons. It is clear that from the obtained results pearl millet grain primed in 200 mg/L SA along with B at a rate of 3 kg/fed could be recommended for enhancing pearl millet yields under saline soil conditions.

Keywords: Boron, Pearl millet, Salicylic acid, Salinity, Yield and its components.

Introduction

Soil salinity is a principle abiotic stress for crop production in numerous districts of the world, particularly in the parched and semi-dry areas (Yadav et al., 2012). Around 33% of the irrigated soils within the world are now influenced by fluctuating levels of saltiness/sodicity (Khan & Abdullah, 2003). South Sinai in Egypt is a dry land with high evapotranspiration and saline groundwater. This groundwater is the dominant source of water for irrigating the soils right now (Reiad et al., 2014). Management of saline soils by flushing out of salts using clean water is costly and is limited by the availability of clean water. Thus, the use of salinity-tolerant plants is one available option. Pearl millet (*Pennisetum glaucum* (L.) R. Br.) having high inbuilt tolerance to saline soils might serve a useful function and may be grown in saline lands for grain and forage production (Yadav et al., 2012).

There is a persistent need for enhancing the productivity of cereal crops in Egypt these days to supply a growing population. This enhancement must take place despite the harsh conditions of the region including scarcity of water, drought, and severity of climate change as well as the intrinsic

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soil properties augments in the cultivated saline and infertile areas. In Egypt, pearl millet is grown fundamentally as a feed crop in summer, whilst different nations of Africa and Asia; it is the staple grain crop in rustic locales for nourishment (Reiad et al., 2014). Pearl millet is a strong, harsh climate-adapted grain crop, ideal as a model to test abiotic and biotic stresses. It has a high crop development rate, enormous leaf area index, and high radiation use effectiveness that supports its high potential yield (Shivhare & Lata, 2017; Ullah et al., 2017; Kadivala et al., 2019). It can thus support the fight against poverty and lack of nourishment due to its resilience to climate calamities (Jukanti et al., 2016; Rijsberman, 2014; Ndiku et al., 2014). Furthermore, it has incredible potential as a sustainable staple food and forage crop, especially in parched and semi-parched areas of the world threatened by environmental changes (Kadivala et al., 2019; Taylor, 2019).

Salicylic acid (SA) stimulates the plant's resistance responses to alleviate oxidative harm induced by salt stress. In saline conditions, (100–150 mM NaCl) just half of Arabidopsis seeds germinate, however, in the presence of SA (0.05–0.5mM) seed germination increases to 80% (Vicente & Plasencia, 2011). Exogenous applications of salicylic acid strongly inhibited Na^+, K^+, Ca^{2+}, and Cl^- and organic solute accumulations but stimulated N and relative water content (RWC), (Shirasu et al., 1997). Comparable outcomes were reported under abiotic stresses by other studies (Rajjou et al., 2006; Alonso-Ramirez et al., 2009).

Micronutrient deficiencies are becoming increasingly common in agriculture due to increased removal due to high yielding; high uptake crops (Kadivala et al., 2019). Application of boron (B) alleviates the toxicity of aluminum by regulating the activities of antioxidant enzymes, proline, secondary metabolite contents, stabilizing integrity of the proteins, and reducing reactive oxygen species and Al concentrations (Riaz et al., 2018). Boron's inadequacy in plants diminishes the biomass and disturbs the carbohydrate and phenol metabolism (Dugger, 1983). In many plant species, including cereals, an inadequate supply of B decreases the monetary yield (Misra & Patil, 1987), chiefly due to the marked reduction and retardation in flowering and fruit development under B inadequacy.

Inadequate information is available concerning the synergistic effect of SA and B on pearl millet yield and its components, particularly under salinity stress. Thus, the objectives of the present study were to evaluate the performance of pearl millet under salt stress conditions and examine the potency of salicylic acid and boron in improving the productivity of pearl millet plants under marginal environments in to achieve and secure sustainable development goals, mainly the fight against poverty and food insecurity.

Materials and Methods

Site description

A two-year field experiment was carried out at the Agricultural Experimental station of Ras-Sudr, Desert Research Center (DRC), South Sinai Governorate located at (30° 34\ N and 31° 34\ E), Egypt, during the two summer growing seasons of 2018 and 2019. The mechanical and physical (Table 1), and chemical (Table 2), analysis of the experimental soil are given below. The mechanical analysis was carried out according to methods of Jackson (1958). Chemical analysis was carried out according to methods of Jackson (1958) and Chapman & Pratt (1961). The soil is a calcareous sandy loam. Chemical analysis of the irrigation water appears in Table 3. The previous crop was barley in both seasons.

Experimental treatments and design

The study included two tested factors, i.e. seed priming (seed soaking) in five salicylic acids (SA) levels (tap water as a control, 50, 100, 150 and 200mg/L SA) and soil application of five boron (B) rates (without boron, 1.0, 2.0, 3.0 and 4.0kg B/fed, as boric acid). Seeds were soaked for 8 hours and then air-dried before sowing. Note: feddan (fed) = 4200m^2.

A split-plot design with three replicates was used. SA treatments were arranged in the main plots, while B rates were distributed within the sub-plots. The trial unit area was 10.5m^2 containing five ridges (3.5m length and 60cm apart).

On May 12th and 16th in 2018 and 2019 seasons, respectively, a grain of pearl millet CV. Shandaweel–1 was planted in hills, 20cm apart at a rate of 12.0kg/fed. At 21 days after sowing; plants were thinned to one plant per hill. Nitrogen fertilizer was added at the rate of 70kg N/fed in the form of ammonium sulfate (20% N) at three equal doses: after thinning, and before the second and the third irrigation. Phosphorus fertilizers (calcium superphosphate, 15.5% P_2O_5) at a rate of 30kg P_2O_5/fed and organic manure at a rate of 20m^3/fed. were added during soil preparation. Potassium fertilizer was applied in the form of potassium sulfate (48% K_2O) at a rate of 75kg K_2O/fed at 50 days after sowing. Groundwater was the source of irrigation and applied through the gated pipe irrigation system. All other endorsed agricultural practices were adopted throughout the two experimental seasons.

Sampling and assessments

Yield traits

At harvest (150 days after sowing), ten guarded plants were taken randomly from each plot to measure plant height, panicle length, panicles number/m^2, grain weight/panicle, 1000–grain weight (seed index). Moreover, whole plants of the plot were collected to measure biological and grain yields/fed.

Grain nitrogen content

Total nitrogen was determined in grains using the modified micro Kjeldahl technique as defined in AOAC (2005). The crude protein content % was calculated by multiplying the total nitrogen % by 6.25. Then protein yield kg/fed was calculated, Protein yield (kg/fed)= Grain yield (kg/fed) × grain protein content percentage.

Statistical methods

All the obtained data of each season were statistically analyzed using the appropriate analysis of variance by Gomez & Gomez (1984). Means were compared by using (LSD) check at 0.05 level of significance.

TABLE 1. Mechanical and physical analysis of the experiment soil.

Depth (cm)	Coarse sand (0.5–1.0mm)	Fine sand (0.1–0.25mm)	Silt (0.002 - 0.05mm)	Total sand (0.1-1mm)	Clay (< 0.002mm)	Class texture
0-30	21.25	58.18	10.49	79.43	10.08	Sandy loam
30-60	22.70	62.50	7.43	85.20	7.39	Sandy loam

TABLE 2. Chemical analysis of the experiment soil.

Depth (cm)	pH	EC (dS m^{-1})	$CaCO_3$ (%)	Saturation soluble extract (mg/100g)							Available nutrients (mg kg^{-1})			
				Cations			Anions							
				$Ca^{=}$	Mg^{++}	Na^{+}	CO_3^{-}	$HCO_3^{=}$	Cl^{-}	$SO_4^{=}$	N	P	K	B
0-30	7.75	8.71	60.14	24.80	5.50	57.45	0.0	6.10	61.6	22.8	26.1	5.15	51.49	0.23
30-60	7.89	7.34	54.10	17.0	3.95	49.65	0.0	3.60	49.55	19.9	18.55	3.45	35.35	0.15

TABLE 3. Chemical analysis of the irrigation water.

EC (dS m^{-1})	pH	Soluble anions (meq/L)				Soluble cations (meq/L)			
		CO3$^{=}$	HCO_3^{-}	$SO_4^{=}$	Cl^{-}	Ca^{++}	Mg^{++}	Na^{+}	K^{+}
9.8	7.7	0.00	2.48	30.83	46.18	17.38	13.71	42.81	0.37

Results and Discussion

The data outcomes in Tables 4, 5, and 6 can be presented and interpreted under the three main headings as follows:

Effect of salicylic acid (SA)

Pearl millet yield and its attributes and grain protein content were markedly affected by SA treatments in both the 2018 and 2019 seasons (Table 4). The findings indicate that plant height, panicle length, panicles number/m^2, grain weight/panicle, seed index, and grain protein content percentage, as well as biological, grain, and protein yields/fed, were progressively increased with increasing SA levels in both seasons. Pearl millet grains soaked in 200mg/L SA treatment gave the greatest values. Respectively the values for these characters were increased by 21.7, 41.2, 36.9, 58.2, 103.5, 36.4, 93.1, 92.5, and 161.9%, in the 1st season as well as 21.4, 34.5, 36.7, 54.3, 100, 35.9, 88.6, 87.7 and 155%, in the 2nd season, respectively, as compared to no SA application (tap water only).

TABLE 4. Effect of salicylic acid and boron levels on pearl millet yields, its components and grain protein content percentage (2018 and 2019 seasons).

Treatments	Plant height (cm)	Panicle length (cm)	Panicles number/ m^2	Grain weight/ panicle (g)	1000 grain weight (g)	Grain protein content (%)	Yield (kg/fed)		
							Biological	Grain	Protein
2018 season									
Salicylic acid									
SA_1	144.5	24.3	57.2	6.7	5.7	8.8	893.2	289.1	25.5
SA_2	148.9	26.4	65.8	8.3	7.5	10.0	1217.5	405.6	40.7
SA_3	155.8	29.2	68.7	10.0	9.3	11.0	1542.3	488.8	54.0
SA_4	169.9	33.1	76.6	10.2	10.7	11.9	1650.6	512.5	61.0
SA_5	175.9	34.3	78.3	10.6	11.6	12.0	1724.3	556.4	66.8
LSD (0.05)	1.20	0.48	0.62	0.04	0.05	0.11	4.78	4.49	0.68
Boron									
B_1	144.9	25.5	60.9	8.1	7.8	10.3	1239.2	386.1	41.0
B_2	151.8	27.6	66.0	9.1	8.9	10.6	1337.8	425.2	46.1
B_3	160.3	29.7	70.5	9.4	9.2	10.8	1418.0	456.1	50.3
B_4	170.7	32.8	75.7	9.7	9.5	11.1	1552.3	501.2	56.6
B_5	167.1	31.5	73.4	9.6	9.4	10.9	1480.7	483.7	53.9
LSD (0.05)	1.89	0.51	1.02	0.08	0.06	0.12	9.73	6.72	0.90
2019 season									
Salicylic acid									
SA_1	146.6	26.4	58.8	7.0	5.9	8.9	928.3	301.9	26.9
SA_2	151.3	27.8	67.7	8.6	7.8	10.1	1251.1	417.8	42.4
SA_3	158.4	29.7	70.7	10.2	9.5	11.2	1572.4	500.1	55.9
SA_4	173.1	33.7	79.3	10.5	10.9	12.0	1688.1	524.9	63.3
SA_5	178.0	35.5	80.4	10.8	11.8	12.1	1751.0	566.6	68.6
LSD (0.05)	1.18	0.25	0.80	0.06	0.06	0.11	6.04	4.95	0.69
Boron									
B_1	148.2	26.7	63.3	8.3	8.3	10.4	1288.4	403.8	43.2
B_2	154.2	28.6	68.0	9.4	9.1	10.7	1369.8	436.0	47.8
B_3	162.3	30.8	72.2	9.7	9.3	10.9	1441.9	463.9	51.7
B_4	173.7	34.4	78.2	10.1	9.8	11.3	1589.2	514.6	59.1
B_5	169.0	32.6	75.2	9.8	9.5	11.0	1501.6	492.8	55.4
LSD (0.05)	1.77	0.42	0.97	0.08	0.06	0.13	8.06	6.42	0.95

- SA_1, SA_2, SA_3, SA_4 and SA_5 mean 0.0, 50, 100, 150 and 200mg/L salicylic acid, respectively.
- B_1, B_2, B_3, B_4 and B_5 mean 0.0, 1.0, 2.0, 3.0 and 4.0kg boron/fed, respectively.
- LSD is Least Significant Difference.

TABLE 5. Effect of salicylic acid treatments and boron levels interaction on pearl millet yields, its components and grain protein content percentage (2018 season).

Treatments		Plant height (cm)	Panicle length (cm)	Panicles number/ m²	Grain weight/ panicle (g)	1000 grain weight (g)	Grain protein content (%)	Yield (kg/fed)		
SA	B							Biological	Grain	Protein
SA_1	B_1	127.0	21.0	46.0	5.6	4.4	8.2	707.0	210.7	17.3
	B_2	135.00	22.0	53.0	6.8	5.7	8.6	823.3	261.0	22.5
	B_3	146.3	24.0	59.3	7.0	5.9	8.8	907.6	295.3	26.0
	B_4	158.3	27.7	65.7	7.2	6.3	9.2	1051.7	350.7	32.2
	B_5	155.7	26.6	62.0	7.1	6.2	9.0	976.3	327.6	29.6
SA_2	B_1	135.6	21.3	56.0	7.1	6.1	9.5	1033.6	330.0	31.4
	B_2	143.0	24.3	62.0	8.3	7.3	9.8	1151.6	376.7	36.9
	B_3	151.0	27.0	67.0	8.5	7.7	10.1	1238.0	412.3	41.6
	B_4	159.3	30.0	73.0	8.8	8.2	10.4	1369.3	466.0	48.5
	B_5	155.3	29.3	71.0	8.7	8.1	10.2	1295.0	443.0	45.2
SA_3	B_1	142.7	25.0	61.7	8.7	8.0	10.5	1360.6	422.6	44.4
	B_2	149.0	28.0	66.0	9.9	9.4	10.8	1471.3	463.6	50.1
	B_3	156.3	29.3	70.0	10.2	9.5	11.0	1554.7	491.7	54.1
	B_4	167.0	32.3	73.7	10.7	9.9	11.5	1703.0	543.6	62.5
	B_5	164.0	31.3	72.0	10.5	9.8	11.3	1621.6	522.3	59.0
SA_4	B_1	156.3	29.3	69.0	9.3	9.8	11.4	1503.3	466.0	53.1
	B_2	163.0	31.3	74.0	9.9	10.6	11.7	1588.0	490.3	57.4
	B_3	171.0	34.0	78.0	10.4	10.9	11.9	1662.3	516.6	61.8
	B_4	180.3	36.3	82.0	10.7	11.1	12.3	1777.0	549.7	67.6
	B_5	179.0	34.3	80.0	10.6	11.0	12.1	1722.3	539.6	65.1
SA_5	B_1	163.0	31.0	72.0	9.8	10.9	11.8	1591.3	501.0	58.9
	B_2	169.0	32.3	75.0	10.3	11.6	11.9	1654.6	534.3	63.8
	B_3	177.00	34.3	78.0	10.7	11.7	12.0	1727.3	564.6	68.0
	B_4	188.7	37.7	84.0	11.1	11.9	12.2	1860.3	596.0	72.4
	B_5	181.6	36.0	82.3	10.9	11.8	12.1	1788.0	586.0	70.9
LSD (0.05)		NS	1.14	2.28	0.18	0.13	NS	21.77	15.02	NS

- SA_1, SA_2, SA_3, SA_4 and SA_5 mean 0.0, 50, 100, 150 and 200 mg/L salicylic acid, respectively.
- B_1, B_2, B_3, B_4 and B_5 mean 0.0, 1.0, 2.0, 3.0 and 4.0 kg boron/fed, respectively.
- LSD is Least Significant Difference.
- NS means non-significance at P > 0.05.

TABLE 6. Effect of salicylic acid treatments and boron levels interaction on pearl millet yields, its components and grain protein content percentage (2019 season).

Treatments SA	Treatments B	Plant height (cm)	Panicle length (cm)	Panicles number/ m^2	Grain weight/ panicle (g)	1000 grain weight (g)	Grain protein content (%)	Yield (kg/fed) Biological	Yield (kg/fed) Grain	Yield (kg/fed) Protein
SA_1	B_1	128.3	23.0	48.0	5.8	4.9	8.3	766.3	232.0	19.3
	B_2	137.0	24.3	54.0	7.1	5.8	8.7	852.0	272.0	23.8
	B_3	148.3	26.3	60.3	7.3	6.0	9.0	930.3	302.3	26.9
	B_4	161.3	30.0	68.3	7.7	6.6	9.3	1096.7	365.7	34.0
	B_5	158.0	28.3	63.3	7.3	6.4	9.1	996.0	337.3	30.7
SA_2	B_1	138.6	23.3	59.00	7.4	6.6	9.6	1074.3	347.0	33.3
	B_2	144.7	25.0	64.0	8.7	7.6	10.0	1182.3	386.6	38.4
	B_3	153.0	28.3	68.0	8.8	7.8	10.2	1263.3	419.3	42.8
	B_4	162.0	32.3	75.7	9.2	8.5	10.5	1411.7	481.7	50.9
	B_5	158.3	30.0	72.0	8.9	8.2	10.2	1324.0	454.3	46.7
SA_3	B_1	146.6	25.0	63.0	8.8	8.5	10.5	1400.0	438.0	46.3
	B_2	152.0	28.3	68.0	10.1	9.5	10.9	1501.3	473.3	51.6
	B_3	158.0	30.0	72.0	10.4	9.6	11.2	1573.3	499.0	55.9
	B_4	170.0	33.3	76.3	11.0	10.2	11.7	1738.3	556.3	65.5
	B_5	165.3	32.0	74.0	10.6	9.9	11.3	1649.0	533.7	60.5
SA_4	B_1	161.3	30.0	72.0	9.4	10.2	11.4	1562.3	486.0	55.7
	B_2	166.3	32.0	76.0	10.2	10.8	11.8	1630.3	505.6	60.0
	B_3	173.3	34.3	80.7	10.7	11.0	12.1	1694.3	524.7	63.5
	B_4	183.7	37.0	85.0	11.1	11.4	12.6	1816.0	561.7	70.6
	B_5	180.6	35.3	83.0	10.9	11.2	12.1	1737.6	546.3	66.5
SA_5	B_1	166.0	32.3	74.3	10.0	11.4	11.8	1639.0	516.3	61.1
	B_2	171.0	33.3	78.0	10.7	11.7	12.0	1683.0	542.6	65.1
	B_3	179.0	35.3	80.0	11.0	11.8	12.1	1748.3	574.0	69.5
	B_4	191.3	39.3	86.0	11.4	12.1	12.3	1883.3	607.7	74.8
	B_5	182.6	37.3	83.7	11.1	11.9	12.2	1801.3	592.3	72.4
LSD (0.05)		3.96	0.95	2.18	0.18	0.14	NS	18.02	14.37	NS

- SA_1, SA_2, SA_3, SA_4 and SA_5 mean 0.0, 50, 100, 150 and 200mg/L salicylic acid, respectively.
- B_1, B_2, B_3, B_4 and B_5 mean 0.0, 1.0, 2.0, 3.0 and 4.0 kg boron/fed, respectively.
- LSD is the Least Significant Difference.
- NS means non-significance at P > 0.05.

Because of salinity stress, there can be a production of reactive oxygen species (ROS), including superoxide (O^{2-}), hydrogen peroxide (H_2O_2), singlet oxygen, and hydroxyl radical (Foyer & Noctor, 2003). ROS can significantly disrupt everyday metabolism through oxidative harm to lipids (Alscher et al., 2002), nucleic acids, and proteins (Herbette et al., 2002). The low yields of untreated plants in Table 4 suggested inhibitory effects of salinity on pearl millet yields and its components and protein content. These results are in harmony with Heidari & Jamshidi (2011), who observed that the increase in the salt concentration from control to 12dS m^{-1} reduced grain yield of millet plants by 38.7%. Similar outcomes were obtained by Reiad et al. (2014). They demonstrated that the growth characters and forage yield of pearl millet diminished with increasing saline water levels from 4500 to 8000ppm. Similar trends are supported by Gunes et al. (2007); Elwana & El-Hamahmyb (2009), Karlidag et al. (2009), Yakubu et al. (2010), Hussain et al. (2010). Our salinity level of the water 9.8dS m^{-1} (Table 3) suggests a reduction of about 289.1 and 301.9kg/fed for grain yield in both seasons. This is consistent with the increase in yields observed of 556.4 and 566.6kg/fed in 2018 and 2019 season when high levels of SA were applied to overcome the stress.

Among the techniques used to mitigate the adverse effects of salt stress, seed priming or plant growth regulators are used to enhance the rate and the uniformity of germination in saline soils (Ashraf et al., 2008). The enhancements in pearl millet plant yield and its components and protein content in both 2018 and 2019 seasons as presented in Table 4 and Fig 1. Increasing concentrations of SA might be stimulative on pearl millet plants enabling greater salt tolerance, particularly throughout the seedling stage and to some extent to the vegetative growth stage which is reflected in the reproductive stage. These consequences are in harmony with those obtained by Sivakumar et al. (2002) and Anju et al. (2019).

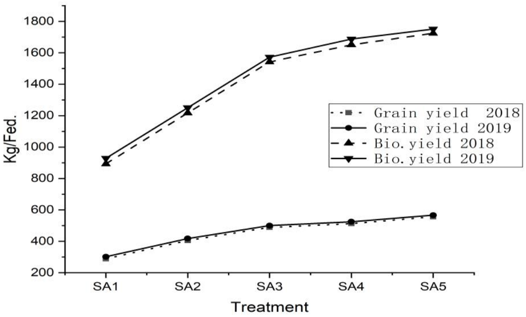

Fig. 1. Effect of salicylic acid on grain and biological yields of pearl milet in 2018 and 2019 seasons.

Salicylic acid priming treatments (from 50 to 200mg/L) possibly enhanced nutrient uptake, physiological activity and transition of reserved food constituent for root and shoot length, in particular at some point of germination (Anju et al., 2019), seedling growth and development stages along with increasing the activity of antioxidant enzymes, Co_2 assimilation and photosynthetic rate (Reza & Rigi, 2014). Additionally, soaking pearl millet grains in SA reduces the overproduction of reactive oxygen species and the harmful effect due to the accumulation of Na^+ and Cl^- ions in roots under salinity stress (Hussain et al., 2010). Many researchers have presented similar conclusions such as Khan et al. (2003); Hussain et al. (2010), Boukraa et al. (2013), Reza & Rigi (2014), Anju et al. (2019). It can be inferred from the results of both 2018 and 2019 growing seasons that seed priming with 200mg/L SA was most effective in mitigating the adverse effects of salinity, enhancing pearl millet plant's productivity in saline soils.

Effect of boron (B)

Regarding the impact of boron treatments on yields, yield components, and protein %, the results in Table 4 showed that all the studied characters were significantly increased by B application in both the 2018 and 2019 seasons. Adding 3.0kg B per feddan attained the highest values of all the studied attributes in both seasons (Table 4). This treatment enhanced plant heights by 17.8 and 17.2%, panicle length by 28.6 and 28.8%, panicles number/m^2 by 24.3 and 23.5%, grain weight/panicle by 19.8 and 21.7%, 1000 grain weight by 21.8 and 18.1% and protein content percentage by 7.8 and 8.7%, as well as biological yield by 25.3 and 23.4%, grain by 29.8 and 27.4% and protein yields by 38.1 and 36.8 % in 2018 and 2019 seasons, respectively compared to no boron addition. The valuable impact of boron treatments at rates of 1.0 to 3.0kg B/fed. on pearl millet yield, yield components, and grain protein content may be due to accumulation of B in different pearl millet plant organs such as shoot, root, stigma, and ovary which results in higher pollination and seed set. Moreover, the crucial impact of B on cell and root elongation, cell division, cell-wall synthesis and stability of plant hormone ranges (Marschner, 1995), also its important role in the elongation of the pollen tube and viability of pollen-grains (Salisbury & Ross, 1992), in turn, encouraged the growth parameters and increased the yields of pearl millet plants under saline stress. These results are supported by the findings of Salisbury & Ross (1992), Salimi et al. (2013), Aftab et al. (2015). However, increasing B rates up to 4.0kg B/fed. resulted in a decrease in all the previously mentioned examined traits in both seasons as shown in Table 4 and Fig 2. This may be due to excessive boron concentrations causing an increase in boron concentration in leaves, stems, and grains to a toxicity level that resulted in a decrease in the biomass of pearl millet plants, thereby lowering the yield and its components. The same trend was noticed by Günes et al. (2011), who found that boron application, i.e. 0, 1, 3, 9 and 12kg B ha^{-1} influenced the yield of corn in the two years of study, and there were significant contrasts between the applications of B. The most significant returns were gotten from 9kg B ha^{-1} rate. These results confirm the work reported by Christensen et al. (2006), Mustafa et al. (2006), Westover & Kamas (2009), Uppal et al. (2015). It was concluded that the maximum production of pearl millet grains relies upon the satisfactory B supply under saline stress.

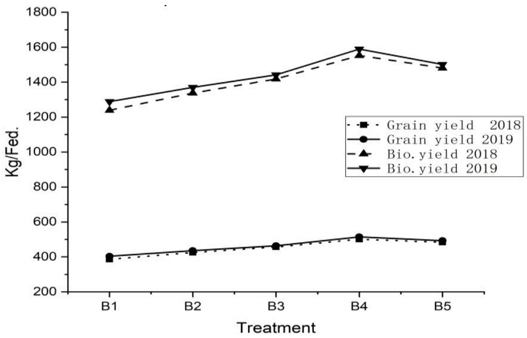

Fig. 2. Effect of boron fertilization on grain and biological yields of pearl milet in 2018 and 2019 seasons.

The lowest values of all studied traits were obtained from plots that received no boron applications in both seasons (Table 4). This result may be due to the negative effects of salinity. Saltiness stress diminishes the uptake and accumulation of important nutrients. Also, salts inhibit germination, seedling growth, development stages, and accelerate senescence of pearl millet plants by osmotic stress (Zeinolabedin, 2012), nutritional inadequacy, and specific ion toxicity (Khatoon et al., 2010). These outcomes are upheld by observations of Yakubu et al. (2010) and Zeinolabedin (2012).

Effect of interaction

The data in Tables 5 and 6 demonstrated the large impact of the interaction among SA treatments and boron levels on pearl millet plant yields and its traits in the 2018 and 2019 growing seasons, except plant height in the first season, grain protein content % and protein yield in both seasons. The effective combination of pearl millet seed priming in 200mg/L SA with adding B at a rate 3.0kg/fed recorded the highest values for plant height in the second season only, panicle length, panicles number/m^2, the heaviest grain weight/panicle and seed index (1000 grain weight) as well as grain and biological yields in the two seasons. While the interaction between pearl millet plant grains primed without SA with no B application gave the minimal values for all studied characters in both 2018 and 2019 seasons as illustrated in Tables 5 and 6.

The combination of 200mg/L SA as a seed priming treatment with boron at a rate of 3.0kg/fed had a synergistic effect and showed a substantial impact on all the studied characters as introduced in Tables 5 and 6. These results may be due to the positive effect of SA along with B to ameliorate the saltiness and promote the nutrients uptake and mobilization from germination to reproductive stages under saltiness stress, in turn, reflected improving the productivity of pearl millet.

Conclusion

It could be concluded that under saline conditions, seed priming in 200mg/L SA with the addition of 3.0kg B/fed in the field could be suggested for increasing pearl millet productivity. The judicious application of SA and B fertilizer together being environmentally friendly can be recommended for farmers to use in their fields to mitigate the saline stress. Ultimately, the present results warrant further studies and researches on the foliar spray application of SA and B to explore and track their pathways in pearl millet plants.

Pearl millet is an appropriate choice to combat water scarcity, population increase, and climate change in conjunction with increasing salinity, drought, infertile soils, and land degradation in Egypt. The crop can make contributions to the fight against poverty and food insecurity to accomplish sustainable development goals, especially in marginal environments.

References

Aftab, M., Haq Maul, A.J., Waraich, E.A. (2015) Salinity and B tolerance in cotton (*Gossypium hirsutum*) varieties: a short-term hydroponic study. *Int. J. Agric. Biol.* **17**, 797-802.

Alonso-Ramirez, A., Rodriguez, D., Reyes, D., Jimenez, J.A., Nicolas, G., Lopez-Climent, M., Nicolas, C. (2009) Evidence for a role of gibberellins in salicylic acid-modulated early plant responses to abiotic stress in Arabidopsis seeds. *Plant Physiology*, **150**(3), 1335-1344.

Alscher, R.G., Erturk, N., Heath, L.S. (2002) Role of superoxide dismutases (SODs) in controlling oxidative stress in plants. *Journal of Experimental Botany*, **53**, 1331-1341.

Anju, U.L., Doddagoudar, S.R., Pattanashetti, S.K., Basave Gowda, Vijaykumar, K. (2019) Influence of seed priming on seed germination, seedling growth, peroxidase activity, proline and total soluble sugar content of pearl millet (*Pennisetum glaucum* L.) under salinity stress. *International Journal of Chemical Studies*, **7**(5), 508-514.

AOAC (2005) Association of official agriculture chemists. "*Official Methods of Analysis*", 18th ed., 2nd Version. Gaithersburg, MD: USA.

Ashraf, M., Athar, H.R., Harris, P.J.C., Kwon, T.R. (2008) Some prospective strategies for improving crop salt tolerance. *Adv. Agron.* **97**, 45-110.

Boukraa, D., Benabdelli, K., Belabid, L., Bennabi, F. (2013) Effect of salinity on chickpea seed germination pre-treated with salicylic acid. *Sci. J. Biol. Sci.* **2**(4), 86-93.

Chapman, H.D., Pratt, P.F. (1961) "*Methods and Analysis for Soils, Plants, and Waters*". Univ. Calif. Div. Agr. Sci., Berkeley, 309p.

Christensen, L.P., Beede, R.H., Peacock, W.L. (2006) Fall foliar sprays prevent boron-deficiency symptoms in grapes. *California Agriculture*, (60)2. University of California, Divison of agriculture and Natural Resources, Berkeley, CA, ETATS-UNIS.

Dugger, W.M. (1983) Boron in plant metabolism. In: "*Encyclopedia of Plant Physiology"*(new series) 158, pp. 626-650. Springer· Verlag, Berlin-New York.

Elwana, M.W.M., El-Hamahmyb, M.A.M. (2009) Improved productivity and quality associated with salicylic acid application in greenhouse pepper. *Scientia Horticulturae*, **122**(4), 521-526.

Foyer, C.H., Noctor, G. (2003) Redox sensing and signaling associated with reactive oxygen in chloroplasts, peroxisomes and mitochondria. *Physiologia Plantarum*, **119**, 355-364.

Gomez, K.A., Gomez, A.A. (1984) "*Statistical Procedures for Agricultural Research*", pp. 95-109, 2nd ed. Jhon Wiley and Sons Inc, New York, USA.

Gunes, A., Inal, A., Alpaslan, M., Eraslan, F., Bagci, E.G., Cicek, N. (2007) Salicylic acid-induced changes on some physiological parameters symptomatic for oxidative stress and mineral nutrition in maize (*Zea mays* L.) grown under salinity. *J. Plant Physiol.* **164**, 728-736.

Günes, A., Ataoğlu, N., Esringü, A., Uzun, O., Ata, S., Turan, M. (2011) Yield and chemical composition of corn (*Zea Mays* L.) as affected by boron management. *International Journal of Plant, Animal and Environmental Sciences,* **1**(1), 42-53.

Heidari, M., Jamshidi, P. (2011) Effects of salinity and potassium application on antioxidant enzyme activities and physiological parameters in pearl millet. *Agricultural Sciences in China*, **10**(2), 228-237.

Herbette, S., Lenne, C., Leblanc, N., Julien, J.L., Drevet, J.R., Roeckel- Drevet, P. (2002) Two GPX-like proteins from Lycopersicon esculentum and Helianthus annuus are antioxidant enzymes with phospholipid hydroperoxide glutathione peroxidase and thioredoxin peroxidase activities. *European Journal of Biochemistry*, **269**, 2414-2420.

Hussain, K., Nawaz, K., Majeed, A., Khan, F., Lin, F., Ghani, A., Raza, G., Afghan, S., Zia-ul-hussnain, S., Ali, K., Shahazad, A. (2010) Alleviation of salinity effects by exogenous applications of salicylic acid in pearl millet (*Pennisetum glaucum* (L.) R. Br.) seedlings. *African Journal of Biotechnology*, **9**(50), 8602-8607.

Jackson, M.L. (1958) "*Soil Chemical Analysis*". Prentice-Hall, Englewood Cliffs, NJ, USA.

Jukanti, A.K., Gowda, C.L.L., Rai, K.N., Manga, V.K., Bhatt, R.K. (2016) Crops that feed the world 11. Pearl millet (*Pennisetum glaucum* L.): An important source of food security, nutrition and health in the arid and semi-arid tropics. *Food Security*, **8**, 307-329.

Kadivala, V.H., Ramani, V.P., Patel, P.K. (2019) Effects of multi-micronutrient mixture on growth, yield and quality of the summer pearl millet (*Pennisetum glaucum* L.). *International Journal of Current Microbiology and Applied Sciences*, **8**(4), 783-790.

Karlidag, H., Yildirim, E., Turan, M. (2009) Salicylic acid ameliorates the adverse effect of salt stress on strawberry. *J. Agric. Sci.* **66**, 271-278.

Khan, A.A., Abdullah, Z. (2003) Salinity-sodicity induced changes in reproductive physiology of rice (*Oryza sativa* L.) under dense soil. *Environment and Experimental Botany*, **47**, 145-157.

Khan, W., Prithviraj, B., Donald, S.L. (2003) Photosynthetic responses of corn and soybean to foliar application of salicylates. *J. Pl. Physiol.* **160**, 485-492.

Khatoon, T., Hussain, K., Majeed, A., Nawaz, K., Nisar, M.F. (2010) Morphological variations in Maize (*Zea mays* L.) under different levels of NaCl at germinating stage. *World Appl. Sci. J.* **8**(10), 1294-1297.

Marschner, H. (1995) "*Mineral Nutrition of Higher Plants*". 2nd ed. Academic press, San Diego, CA.

Misra, S.M., Patil, B.D. (1987) Effect of boron on seed yield in lucerne (*Medicago sativa* L.). *Journal of Agronomy and Crop Science,* **158**(1), 34-47.

Mustafa, E.A.M., El-Shamma, M.S., Hagagg, L.F. (2006) Correction of B deficiency in grapevines of Bez- El-Anaza Cultivar. *American Eurasian Journal Agriculture and Environmental Science*, **1**, 301-305.

Ndiku, M.H., Jara, E., Sabate, J. (2014) Formative research on acceptability of pearl millet in rural eastern Kenya- A pilot study. *Sustainable Agriculture Research*, **3**, 1-8.

Rajjou, L., Belghazi, M., Huguet, R., Robin, C., Moreau, A., Job, C., Job, D. (2006) Proteomic investigation of the effect of salicylic acid on Arabidopsis seed germination and establishment of early defense mechanisms. *Plant Physiology*, **141**(3), 910-923.

Reiad, M.Sh., Hamada, Maha M.A., Abd EL- Maabou, M.Sh., Khalil, M.H. (2014) Forage growth and productivity of pearl millet as affected by soil mulching, planting date under salinity conditions. *Egypt. J. Agron.* **36**(1), 75-94.

Reza, M.V., Rigi, K. (2014) Effect of salicylic acid in agriculture. *International Journal of Plant, Animal and Environmental Sciences*, **4**(2), 291-296.

Riaz, M., Yan, L., Wu, X., Hussain, S., Aziz, O., Wang, Y., Jiang, C. (2018) Boron alleviates the aluminum toxicity in trifoliate orange by regulating antioxidant defense system and reducing root cell injury. *Journal of Environmental Management*, **208**, 149-158.

Rijsberman, F. (2014) Global alliance for climate smart agriculture. [2016-02-26]. http://dialogues.cgiar.org/blog/ millets-sorghum-climate-smart-grains-warmer-world.

Salimi, S., Moradi, S., Nezhad, K.A., Abdola, A.R. (2013) Growth and yield response of maize (*Zea mays* L. cv . SC704) to different rates of potassium and boron. *Intl. J. Agri. Crop Sci.* **5**(3), 236-240.

Salisbury, F.B., Ross, C.W. (1992) "*Plant Physiology*", 4th ed. Wadsworth Publishing Company, USA.

Shirasu, K., Nakajima, H., Rajashekar, K., Dixon, R.A., Lamb, C. (1997) Salicylic acid potentiates an agonist-dependent gain control that amplifies pathogen signal in the activation of defense mechanisms. *Plant Cell*, **9**, 261-270.

Shivhare, R., Lata, C. (2017) Exploration of genetic and genomic resources for abiotic and biotic stress tolerance in pearl millet. *Frontiers in Plant Science*, **7** (January), 1-17.

Sivakumar, R., Pathmanaban, G., Kalarani, M.K., Vanangamudi, Mallika, Srinivasan, P.S. (2002) Effect of foliar application of growth regulators on biochemical attributes and grain yield in pearl millet. *Indian J. Plant Physiol.* **7**(1), 79-82.

Taylor, John R.N. (2019) Chapter 1- Sorghum and millets: Taxonomy, history, distribution, and production. In: "*Sorghum and Millets*" (2nd ed.) Chemistry, Technology and Nutritional Attributes, pp. 1-21.

Ullah, A., Ahmad, A., Khaliq, T., Akhtar, J. (2017) Recognizing production options for pearl millet in Pakistan under changing climate scenarios. *Journal of Integrative Agriculture*, **16**(4), 762-773.

Uppal, R.K., Wani, S.P., Garg, K.K., Alagarswamy, G. (2015) Balanced nutrition increases yield of pearl millet under drought. *Field Crops Research*, **177**, 86-97.

Vicente, M.R., Plasencia, J. (2011) Salicylic acid beyond defense: Its role in plant growth and development. *J. Expt. Bot.* **62**(10), 3321-3338. https://doi.org/10.1093/jxb/err031.

Westover, F., Kamas, J. (2009) Investigation of spray timing of B and effects of micro-nutrient sprays on yields of Blanc du Bois Wine grapes. *Proceedings of the Texas Viticulture and Enology Research Symposium*, June 2-3., Granbury, Texas.

Yadav, O.P., Rai, K.N., Gupta, S.K. (2012) Pearl millet: Genetic improvement for tolerance to abiotic stresses. In: "*Improving Crop Productivity in Sustainable Agriculture*", 1st ed. Wiley-VCH Verlag GmbH & Co. KGaA., pp. 261-288.

Yakubu, H., Ngala, A.L., Dugje, I.Y. (2010) Screening of millet (*Pennisetum glaucum* L.) varieties for salt tolerance in semi-arid soil of northern Nigeria. *World J. Agric. Sci.* **6**(4), 374-380.

Zeinolabedin, J. (2012) The effects of salt stress on plant growth. *Tech. J. Engin. & App. Sci.* **2**(1), 7-10.

التأثير التعاونى لحامض السالسيليك والبورون على إنتاجية محصول الدخن تحت ظروف الأراضى الملحية المتدهورة

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يعتبر الجفاف والملوحة من العوامل الأكثر تقييدًا لإنتاج المحاصيل في المناطق الجافة وشبه الجافة. علاوة على ذلك، قد تكون زراعة الدخن اختيارًا ممتازًا في الأراضي القاحلة والمالحة. لذلك أجريت تجربتين حقليتين بمركز بحوث الصحراء، محطة التجارب الزراعية برأس سدر، محافظة جنوب سيناء، مصر خلال موسمى النمو 2018 و2019 لدراسة تأثير خمسة معاملات من حامض السالسيليك (نقع الحبوب في الماء فقط، 50، 100، 150 و 200 ملجم/لتر من حامض السالسيليك) وخمسة معدلات من التسميد بالبورون (بدون تسميد بالبورون ،1 2، 3 و4 كجم بورون/فدان) على محصول الدخن ومكوناته. أظهرت النتائج أن صفات ارتفاع النبات (سم)، وطول القنديل (سم)، وعدد القناديل/م2، ووزن الحبوب/قنديل (جم)، ودليل الحبوب (جم) ومحتوى بروتين الحبوب (%)، بالإضافة إلى المحصول البيولوجى ومحصول الحبوب والبروتين (كجم/فدان) زادت معنويا نتيجة تأثيرمستويات حامض السالسيليك في كلا موسمي النمو. كانت معاملة نقع حبوب الدخن في حامض السالسيليك بمعدل 200 ملجم/لتر هى الممارسة الأفضل لجميع الصفات المدروسة في كلا الموسمين مقارنة بالمعاملات الأخرى. فيما يتعلق بتأثير معاملات التسميد بالبورون، تأثرت معنويا جميع الصفات المذكورة أعلاه بمعاملات التسميد بالبورون في كلا الموسمين. أعطت معاملة إضافة 3 كجم بورون/فدان أعلى القيم لجميع الصفات المدروسة في كلا الموسمين. يتضح من النتائج المتحصل عليها أن نقع حبوب الدخن فى حامض السالسيليك بمعدل 200 ملجم/لتر مع التسميد بالبورون بمعدل 3 كجم/فدان هى الممارسة الزراعية الموصى بها لرفع إنتاجية محصول الدخن تحت ظروف التربة الملحية.