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Effect of Potassium Silicate and Salicylic Acid on Salt Tolerance in Okra (*Abelmoschus esculentus* L.)

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Abstract: This study was conducted in a private orchard located in the north of Basra province during the growing season in 2019. The study aimed to investigate the effect of spraying potassium silicate and salicylic acid on the leaves content of chlorophyll and proline and the level of plant hormones (auxins and abscisic acid) in okra leaves under salt stress conditions. The results showed the superiority of spraying treatment with potassium silicate at a concentration of 1.5 g/L^{-1} and salicylic acid at a concentration of 300 mg/L^{-1} significantly in the leaves content of chlorophyll and IAA auxin in the leaves. The same treatment led to a significant decrease in the leaves content of proline and ABA auxin. While, the interaction between the study factors showed a significant effect in the most of studied traits.

Keywords: Okra, Potassium silicate, Salicylic acid, Sodium chloride

Okra, *Abelmoschus esculentus* L., belongs to the family Malvaceae, and it is one of the most important summer vegetable crops. Salinity is one of the major problems facing agriculture on a global scale, especially in arid and semi-arid regions. Okra is classified as one of the medium tolerant plants to salinity, as the ideal level of salinity of irrigation water for the growth of okra plants is 3.4 ds/m^{-1} and that the increase in salinity negatively affects the growth, flowering and yield of the plant (Ünlükara et al 2008). Aziz and Hamid (2021) observed significant decrease in the content of total chlorophyll and potassium in the leaves by increasing the levels of sodium chloride. For the purpose of cultivating okra in lands affected by salinity or irrigated with high levels of saline water, it has become necessary to use some means that increase salt tolerance and work to reduce the harmful effects of salinity, such as external treatments with some plant growth regulators that have proven effective as salicylic acid, as they works on the regulation and uptake of ions, hormonal balance, and photosynthesis (Aziz and Hamid 2021). Over and above, such plant regulators have a great role in protecting plants from the effects of oxidative stress resulting from salt stress (Hayat et al 2012). Several studies have also proven that treatment with some fertilizer compounds, such as potassium silicate, have a significant role in improving plant growth. Silicon is one of the elements that work to resist stress as well as stimulate anti-oxidation systems, and it has many physiological processes, the most important of which are improving the efficiency of photosynthesis, increasing the effectiveness of roots to absorb nutrients necessary for plant growth and development and reducing the toxicity of sodium ion and heavy elements. The potassium has also several functions within plants. Studies have shown that potassium plays an important role in directly or indirectly activating more than 80 enzymes, especially protein-forming enzymes and transporter enzymes (Adrees et al 2015). Therefore, this study was aimed to find out the effect of salinity levels on okra plants on some biochemical and hormonal traits and their response to spraying with potassium silicate and salicylic acid under saline stress conditions (Al-Mawsili 2015).

MATERIAL AND METHODS

The study was conducted during the growing season in 2019 in one of the private fields located in the north of Basra province. The field soil was silt clay analyzed by taking three random samples from different places of the field with different depths ranging from 0-30 cm. Some chemical and physical properties of soil were estimated in the laboratory of the Department of Soil and Water University of Basra (Table 1). The experiment included the effect of three saline concentrations of irrigation water and spraying with potassium silicate and salicylic acid on some biochemical and hormonal characteristics. A randomized complete block design was used with a factorial experiment that included 48 treatments, which is a combination of three concentrations of sodium chloride salt 0, 3, 6 ds m^{-1} and four concentrations of potassium silicate are 0, 0.5, 1, 1.5 (g L^{-1}).) and four concentrations of salicylic acid 0, 100, 200, 300 mg L^{-1} with three replicates for each concentration. Estimates were made for chlorophyll content of leaves (mg g^{-1} fresh weight),

Table 1. Physical and chemical properties of field soil at a depth of 0-30 cm

Properties	Value
Electrical conductivity (E. C) ds/m^{-1}	6.16
PH	8.01
Ready Nitrogen (mg/kg-1)	210.00
Ready phosphorous (mg/kg-1)	24.12
Ready potassium (mg/kg-1)	134.1
% organic matter	0.45
Soil Separators	**%**
Clay	44.8
Silt	40.8
Sand	14.4
Soil texture	Silt clay

the leaf content of proline acid (µg g^{-1} dry matter), the leaf content of abscisic acid (µg kg^{-1} fresh weight) and the IAA auxin content of the leaves (µg g^{-1}).

RESULTS AND DISCUSSION

Total chlorophyll content of leaves (mg gm^{-1} fresh weight): The superiority of plants irrigated with water treated with zero concentration of sodium chloride salt (ds m^{-1}) in this trait compared to their counterparts irrigated with the other two concentrations was observed (Table 2). The plants irrigated with water treated with sodium chloride salt at a concentration of 3 ds m^{-1} significantly outperformed the plants irrigated with water treated with sodium chloride salt at a concentration of 6 ds m^{-1}. Potassium silicate had a significant effect on this trait as well, as spraying plants led to a

Table 2. Effect of potassium and salicylic silicate on the total chlorophyll content of leaves (mg/gm-[1] fresh weight) under saline tension

Salt concentration (ds/m^{-1})	K_2SiO_3 (g/L^{-1})	Salicylic (mg/L^{-1})				K_2SiO_3 **×** salt concentrations
		0	100	200	300	
0	0	3.05	3.16	3.45	3.65	3.32
	0.5	3.64	3.77	3.80	3.90	3.77
	1	3.84	4.07	4.05	4.21	4.04
	1.5	4.12	4.17	4.23	4.33	4.21
3	0	2.73	2.83	2.86	2.94	2.84
	0.5	2.77	2.85	2.90	3.05	2.89
	1	3.02	3.16	3.31	3.51	3.25
	1.5	3.20	3.36	3.42	3.74	3.43
6	0	2.09	2.18	2.24	2.62	2.28
	0.5	2.17	2.31	2.81	2.92	2.55
	1	2.64	2.82	2.96	3.08	2.87
	1.5	2.74	2.85	3.00	3.12	2.92
LSD 0.05					0.17	0.08
Salicylic effect rate		3.00	3.12	3.25	3.42	Salt concentrations
LSD 0.05					0.16	
Salt concentration x salicylic acid	0	3.66	3.79	3.88	4.02	3.84
	3	2.93	3.05	3.o7	3.31	3.09
	6	2.41	2.45	2.75	2.93	2.65
LSD 0.05					0.08	0.05
						Effect K_2SiO_3
K_2SiO_3×Salicylic	0	2.62	2.72	2.91	3.07	2.81
	0.5	2.86	2.97	3.17	3.29	3.09
	1	3.16	3.35	3.44	3.60	3.38
	1.5	3.35	3.46	3.55	3.73	3.47
LSD 0.05					0.09	0.03

significant increase in this trait and was noticed that the effect increased with the increase in the concentration used. The salicylic acid treatment had a significant effect in increasing the chlorophyll content of the leaves, as the plants treated with the concentration of 300 (mg L^{-1}) significantly outperformed the plants of the other treatments.

The results showed that the interaction between irrigation water quality and potassium silicate spraying process had a significant effect on the total chlorophyll content in the leaves. The plants irrigated with water treated with sodium chloride salt at a concentration of zero (dssmans m^{-1}) and treated with potassium silicate at a concentration of 1.5 g l^{-1} gave the highest content of chlorophyll compared to plants irrigated with water containing sodium chloride salts at a concentration of 6 ds m^{-1} and treatment with potassium silicate at a concentration of 0 g L^{-1}.

There were significant differences between the two interaction treatments for the quality of irrigation water and the salicylic spray process, where the highest content of 4.02 mg/gm^{-1} fresh weight was from the plants irrigated with water treated with NaCl at a concentration of 0 ds m^{-1} that was sprayed with salicylic at a concentration of 300 mg L^{-1} compared to its lowest content that of 2.41 mg g^{-1} fresh weight from irrigated plants containing NaCl at a concentration of 6 ds m^{-1} that were not treated with salicylic. The binary interaction between spraying plants with potassium silicate and salicylic also indicated that spraying plants with potassium silicate at a concentration of 1.5 g L^{-1} and salicylic at a concentration of 300 mg L^{-1} gave the highest content of 3.73 mg g^{-1} fresh weight compared to the lowest content of 2.62 mg gm^{-1} fresh weight without spraying the plants with either solution. The triple interaction between the study factors showed a significant effect, as the leaves of plants irrigated with water that were not treated with sodium chloride and treated with potassium silicate at a concentration of 1.5 mg L^{-1} and salicylic acid at a concentration of 300 mg L^{-1} had the highest total chlorophyll content of 4.33 mg g^{-1} in fresh weight compared to the lowest content of 2.09 mg gm^{-1} of fresh weight produced from plants irrigated with water treated with sodium chloride at a concentration of 6 ds m^{-1} and not treated with potassium and salicylic silicate.

Free proline content of leaves (µg/gm-1 dry matter): The study factors and their interactions had a significant effect on the leaf content of proline, as the plants irrigated with water treated with sodium chloride at a concentration of 6 ds m^{-1} were significantly superior to those irrigated with the other two types (Table 3). Potassium silicate had a significant effect on the free proline content of leaves. The spraying with potassium sulfate led to a significant decrease in the leaves content of free proline in all concentrations, and the decrease increased with increasing the concentration used. The interaction between irrigation water quality and potassium silicate had a significant effect on the free proline content of leaves. Plants irrigated with water treated with sodium chloride salt concentrations of 6 ds m^{-1} and not sprayed with potassium silicate gave the highest value of proline in leaves(383.57 µg gm^{-1} dry matter). The lowest value of proline in leaves, was 96.00 µg gm^{-1} dry matters for plants irrigated with water untreated with concentrations of sodium chloride salt sprayed with potassium silicate at a concentration of 1.5 g l^{-1} . The interaction between the quality of irrigation water and salicylic spray indicated significant effect, as the plants irrigated with water treated with sodium chloride salt concentrations of 6 ds m^{-1} and not sprayed with salicylic acid gave the highest value of proline). The lowest value of proline (158.00 µg gm^{-1} of dry matter) was for plants irrigated with water untreated with concentrations of sodium chloride salt and sprayed with salicylic at a concentration of 300 mg l^{-1}.

The interaction between potassium silicates and salicylic indicate was significant effect, as the highest proline in leaves was 218.77 µg gm^{-1} dry matter in plants not sprayed with either solution. The lowest value was 97.86 µg gm^{-1} dry matter in plants sprayed with potassium silicate at a concentration of 1.5 g l^{-1} and salicylic at a concentration of 300 mg l^{-1}. The results of the triple interaction showed that the highest value of proline was 370.30 µg gm^{-1} dry matter in plants irrigated with water treated with sodium chloride salt at a concentration of 6 ds m^{-1} and not sprayed with either of the two solutions. The lowest content was 80.79 µg gm^{-1} dry matter in plants irrigated with water not treated with NaCl and sprayed with salicylic at a concentration of 300 mg L^{-1}.

Leaf content of abscisic acid (µg kg^{-1} fresh weight): The study factors and their interactions had a significant effect on the leaf content of abscisic acid, as the plants irrigated with river water treated with sodium chloride at a concentration of 6 ds m^{-1} were significantly superior to plants irrigated with the other two types (Table 4). The content of abscisic acid decreased significantly in the leaves of plants that sprayed with potassium silicate compared to non-sprayed plants, and the decrease increased with increasing concentration used. Similarly, the content of abscisic acid significantly decreased in the leaves of plants sprayed with salicylic compared to the unsprayed plants. In addition, the interaction between irrigation water quality and spraying with potassium silicate and between irrigation water quality and spraying with salicylic and between spraying with potassium and salicylic silicate showed a significant effect on the leaves content of abscisic acid. The triple interaction showed that the highest value was 199.4 µg kg^{-1} of dry matter resulting from irrigating plants with water treated with sodium chloride salt at a concentration of 6 ds m^{-1} and not sprayed with either of the two solutions. The lowest value was 62.40 µg kg^{-1} dry matter in plants irrigated with water not treated with sodium chloride salt and sprayed with the highest concentration of the two compounds (potassium silicate and salicylic acid).

The superiority of plants irrigated with water treated with zero concentration of sodium chloride salt (ds m^{-1}) in the auxin content of leaves compared to their counterparts irrigated with the other two concentrations was observed (Table 5). The plants irrigated with water treated with sodium chloride salt at a concentration of 3 ds m^{-1}) significantly outperformed the plants irrigated with water treated with sodium chloride salt at a concentration of 6 ds m^{-1}.

The potassium silicate had a significant effect, as spraying plants led to a significant increase in this trait, and the effect increased with the increase in the concentration used. Salicylic treatment had a significant effect in increasing the auxin content of the leaves, and the effect increased with the increase in the concentration used. The plants treated with the concentration of 300 mg L^{-1} were significantly superior in comparison with the other treatments. The interaction between the quality of irrigation water and spraying with potassium silicate had a significant effect on the auxin content, as the plants irrigated with water treated with sodium chloride salt at zero concentration (ds m^{-1}) and treated with potassium silicate at a concentration of 1.5 g l^{-1} gave the highest auxin content, which reached 70.21 µg gm^{-1} fresh weight compared with plants irrigated with water treated with sodium chloride at a concentration of 6 ds m^{-1} and plants treated with potassium silicate at a concentration of 0g l^{-1}, which gave 48.32 µg gm^{-1} fresh weight. The results indicated that there were significant differences between the two interaction treatments for the quality of irrigation water and salicylic spray. The highest content of auxin was (69.49 µg g^{-1}

Table 3. Effect of potassium and salicylic silicates on the free proline content of leaves (µg/gm-1 dry matter) under salt stress

Nacl (ds m^{-1})	K_2Sio_3 (g l^{-1})	Salicylic (mg l^{-1})				Salt concentration K_2Sio_3×
		0	100	200	300	
0	0	225.01	219.60	216.18	211.21	218.00
	0.5	217.30	212.04	209.00	206.70	211.26
	1	205.20	145.70	140.30	133.30	156.65
	1.5	101.71	100.60	100.90	80.79	96.00
3	0	250.00	243.30	225.00	220.30	234.65
	0.5	230.90	221.70	210.70	198.77	215.29
	1	220.60	217.30	216.70	180.70	208.82
	1.5	104.80	111.10	116.10	100.10	108.02
6	0	370.30	357.70	439.30	367.00	383.57
	0.5	296.30	265.20	212.30	180.70	238.62
	1	206.70	155.50	131.80	117.70	152.92
	1.5	106.50	107.01	110.92	112.70	109.28
LSD 0.05			8.91			4.66
Rate of salicylic effect		211.27	196.39	194.10	175.82	Effect of salt concentrations
LSD 0.05			2.96			
Salt Concentration × Salicylic	0	187.30	169.48	166.59	158.00	170.34
	3	201.57	193.35	192.12	174.96	190.50
	6	244.95	221.35	223.58	194.52	221.10
LSD 0.05			4.81			2.52
						Effect of K_2SiO_3
K_2SiO_3 × Salicylic	0	281.77	273.53	293.49	266.17	296.66
	0,5	248.16	232.98	210.66	195.39	221.79
	1	210.83	172.83	162.93	143.9	172.622
	1.5	104.33	106.23	109.30	97.86	104.43
LSD 0.05			5.09			2.88

fresh weight) in the leaves of plants irrigated with water with a concentration of 0 NaCl and sprayed with salicylic at a concentration of 300 mg L^{-1} compared to its lowest content which was (52.74 µg g^{-1} fresh weight) in plants irrigated with water treated with sodium chloride at a concentration of 6 ds m^{-1} and not treated with salicylic acid. The results of the binary interaction also indicated that spraying plants with potassium silicate at concentration of 1.5 g L^{-1} and salicylic at a concentration of 300 mg L^{-1} gave the highest auxin content (71.12 µg g^{-1} fresh weight) compared to its lowest content (55.28 µg g^{-1} fresh weight) in plants that were not sprayed with either solution. The triple interaction between the study factors showed a significant effect, as the leaves of plants irrigated with water not treated with sodium chloride but treated with potassium silicate at a concentration of 1.5 mg L^{-1} and salicylic acid at a concentration of 300 mg L^{-1} contained the highest auxin content (75.65 µg gm^{-1} fresh weight) compared to the lowest content 46.46 µg gm^{-1} in plants irrigated with water treated with sodium chloride at a concentration of 6 ds m^{-1} and not treated with both solutions.

The low content of chlorophyll in leaves as a result of plant irrigation with water containing high concentrations of sodium chloride is attributed to the fact that salinity may cause damage to membranes resulting in direct damage to photosynthetic pigments. It may also be attributed to the toxic effect of sodium and chlorine ions on leaf tissues at high salinity, which may lead to the destruction of chlorophyll pigments, as these two toxic ions replace magnesium in the synthesis of chlorophyll and thus lead to its dissolution (Qu et al 2012). Furthermore, foliar spraying with potassium silicate, which led to an increase in chlorophyll content, may be the reason that it contains silicon ion because of its important physiological roles, the most important of which is improving the efficiency of photosynthesis, increasing the effectiveness of roots in

Table 4. Effect of potassium and salicylic silicate on abscisic acid (µg/kg fresh weight) in leaf under saline tension

Nacl (ds m^{-1})	K_2Sio_3 (g l^{-1})	Salicylic (mg l^{-1})				Salt concentration K_2Sio_3×
		0	100	200	300	
0	0	147.90	138.80	108.90	99.90	123.88
	0.5	129.60	123.00	94.80	85.90	108.33
	1	103.40	97.80	95.50	75.30	93.00
	1.5	108.90	94.80	85.80	62.40	87.98
3	0	176.30	170.40	165.90	119.40	158.00
	0.5	173.6	153.6	151.40	119.10	149.43
	1	169.20	152.70	153.60	105.90	145.35
	1.5	156.80	102.80	106.10	101.50	116.80
6	0	199.4	191.8	184.70	110.30	171.55
	0.5	190.20	153.60	131.30	131.30	151.60
	1	196.70	111.80	179.10	103.40	147.75
	1.5	155.1	131.3	131.3	102.50	130.40
LSD 0.05				10.56		5.28
Rate of salicylic effect		158.93	135.20	132.37	101.41	Effect of salt concentrations
LSD 0.05				3.63		
Salt concentration × Salicylic	0	122.45	113.60	96.25	80.88	103.29
	3	168.98	144.88	144.25	111.48	142.39
	6	185.35	147.13	156.60	111.88	150.24
LSD 0.05				5.28		2.64
						Effect of K_2SiO_3
K_2 Sio_3 × Salicylic	0	174.53	167.00	153.17	109.87	151.14
	100	164.47	143.40	125.83	112.10	136.45
	200	156.43	120.77	142.73	94.87	128.70
	300	140.27	109.63	107.73	88.80	111.61
LSD 0.05				6.25		3.63

Table 5. Effect of potassium and salicylic silicate on the auxin content of leaves (µg.gm fresh weight^{-1}) under saline tension

Nacl (ds m^{-1})	K_2Sio_3 (g l^{-1})	Salicylic (mg l^{-1})				Salt concentration K_2Sio_3×
		0	100	200	300	
0	0	54.91	57.90	57.00	63.20	58.25
	0.5	65.85	63.44	65.27	67.24	65.45
	1	66.01	70.25	71.77	71.85	69.97
	1.5	64.29	69.44	71.45	75.65	70.21
3	0	64.48	68.83	64.36	63.87	65.39
	0.5	66.66	64.98	61.78	63.09	64.13
	1	63.02	67.32	62.50	64.13	64.24
	1.5	69.54	67.28	74.06	74.33	71.30
6	0	46.46	49.47	48.60	48.79	48.33
	0.5	49.90	50.89	52.41	53.04	51.56
	1	54.31	55.07	56.03	58.31	55.93
	1.5	60.28	65.03	63.76	63.64	63.18
LSD 0.05			4.51			2.00
Rate of salicylic effect		60.48	62.49	62.42	63.93	Effect of salt concentrations
LSD 0.05			1.37			
Salt concentration × salicylic	0	62.77	65.26	66.37	69.49	65.97
	3	65.93	67.10	65.68	66.36	66.26
	6	52.74	55.12	55.20	55.95	54.75
LSD 0.05			2.26			1.30
						Effect of K_2SiO_3
K_2 Sio_3 × salicylic	0	55.28	58.73	56.65	58.62	57.32
	0.5	60.80	59.77	59.82	61.12	60.38
	1	61.11	64.21	63.43	64.76	63.38
	1.5	64.70	67.25	69.76	71.21	68.23
LSD 0.05			2.61			1.18

absorbing nutrients and reducing sodium ion toxicity (Adrees et al 2015). Potassium also has a role in improving the efficiency of the second photosystem (Akram and Muhammad 2009). The accumulation of amino acid proline in the tissues of plants exposed to conditions of salt stress may be due to an increase in protein hydrolysis due to the salinity of irrigation water as a result of the increase in the activity of the protease enzyme under salt stress conditions to release amino acids, including proline to be stored, transported or used in osmotic modification (Azooz 2004) and this is a kind of adaptation to protect the plant in such conditions. The external addition of potassium silicate led to a decrease in the amount of proline in plant leaves, meaning that the biosynthesis of proline decreases with an increase in concentration in saline conditions, and this indicates that the proline plays a role in osmotic adjustment. Wan et al (2004) observed that abscisic acid works on regulating the water condition of the plant and regulating water channels or stomata conduction. Salt stress caused a decrease in the level of plant hormones(IAA) and an increase in Abscisic acid (ABA), as well as a hormonal imbalance. The treatment with potassium silicate and salicylic acid reduced the effect of salt stress on the plant by increasing the absorption of nutrients and the production of auxin IAA (Taiz and Zeiger 2006). The results obtained indicate that when plants treated with salicylic acid may have positive effects on the physiological aspects of plants under inappropriate environmental stress conditions.

CONCLUSION

The use of potassium silicate and salicylic acid in certain concentrations had a significant effect on the content of chlorophyll and IAA auxin in the leaves. The interaction between most of the study factors also had significant effect on most of the studied traits.

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