

Physiological and productive response of wheat plants under the influence of irrigation water salinity when treated with potassium and salicylic acid

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Abstract. *This study is aimed at establishing the importance of potassium fertilization with salicylic acid in amounting capability of wheat plant to offset with the salinity stress caused by irrigation water salinity. The pot experiment was designed with three replicates of Randomised Complete Block Design (RCBD) to investigate the effect of four irrigation water salinity levels (2 dS m^{-1} , 4 dS m^{-1} , 6 dS m^{-1} , 8 dS m^{-1}), three salicylic acid concentration levels (0, 150 and 300 mg L^{-1}), and two level of potassium fertilization. The results showed that increasing salinity levels led to higher accumulation of sodium and proline in the grains, accompanied by a significant reduction in potassium concentration and some physiological traits related to growth and productivity. The results also indicated that treatment with salicylic acid and potassium fertilisation helped improve ionic balance within the plant and reduce the harmful effects of salinity stress. By reducing sodium accumulation, increasing potassium content, and improving growth efficiency. The interactions between the study factors, both two-way and three-way, showed significant differences in most of the traits studied, with treatments that combined the lowest salinity level with the addition of potassium and a high concentration of salicylic acid achieving the best results in improving yield traits and reducing salinity-related damage. The study concludes that the integration of potassium fertilisation and salicylic acid spraying is an effective method to enhance wheat plant tolerance to salinity stress and maintain its productive efficiency under saline irrigation conditions.*

Keywords: *wheat; water salinity; fertilizer potassium; salicylic acid*

1. INTRODUCTION

signaling molecule that stimulates the formation of defence compounds and enhances the efficiency of the antioxidant system, such as the enzymes catalase and peroxidase, thereby

reducing the accumulation of reactive oxygen species and limiting cellular membrane damage. It also helps maintain chlorophyll content, improve photosynthetic efficiency, regulate stomatal function, and enhance ionic balance within cells under salinity conditions [1] Wheat (*Triticum aestivum* L.) is considered one of the most important strategic crops in the world due to its essential role in achieving food security, especially in developing countries and arid and semi-arid regions. However, its productivity in Iraq is still affected by a number of environmental factors, with salinity stress being at the forefront due to its widespread prevalence and direct impact on the physiological processes of the plant and yield components [2] Many recent studies have indicated that salinity is one of the main factors limiting wheat productivity due to its negative impact on physiological processes, ionic balance and the metabolic efficiency of the plant, which directly affects growth traits and yield [3]. Although numerous studies have addressed the effects of potash fertilisation or salicylic acid individually, the study of their interaction under different levels of irrigation water salinity still requires further research, particularly under local environmental conditions. Therefore, this study was conducted to evaluate the role of potash fertilisation and salicylic acid in enhancing wheat tolerance to salt stress and improving its physiological growth and productivity under various salinity conditions Accordingly the study aimed to:

1-Examine the effect of irrigation water salinity on the germination, growth and productivity of wheat.

2-Evaluate the role of potassium fertilisation and salicylic acid in mitigating the effects of salt stress.

3-Determine the efficiency of the interaction between salinity and the enhancing treatments in improving the physiological and productive traits of wheat.

2. MATERIALS AND METHODS

2.1. MATERIALS

2.1.1 Experimental site: The pot experiment for the year 2025-2026 was conducted in the field of the Technical College - Al-Musayyib, located within the Al-Musayyib project area, at coordinates 32°36'59"N and 44°22'25"E, to study the effect of potassium fertilization and salicylic acid on wheat tolerance to irrigation water salinity.

2.1.2. Soil Preparation: soil samples were taken at random from the field up to a depth, 0-30 cm and mixed together to get a good blend. The sample material tested was a composite sample air dried, pounded with a hammer and sifted through a 2 mm sieve. The following table lists some of the soil's physical and chemical properties, which were estimated prior to planting, Table No. (1).

Table 1. Some physical and chemical properties in the soil field.

<i>Capacity</i>	<i>Value</i>	<i>Measurement Unit</i>
<i>Soil (pH)</i>	7.4	
<i>Electrical Conductivity (EC)</i>	2.3	<i>dS m⁻¹</i>
<i>Cation Exchange Capacity (CEC)</i>	19.6	<i>Centimole kg⁻¹ soil</i>

Ca^{2+}	8.65	$m\ mol.L^{-1}$
Mg^{2+}	6.9	
Na^{+}	19.89	
Cl^{-}	22.2	
SO_4^{2-}	6.3	
CO_3^{2-}	Nil	
HCO_3^{-}	8.6	
Bulk density	1.34	$Mg.m^{-3}$
Soil organic matter (S.O.M.)	7.78	$g\ kg^{-1}\ soil$
Available nitrogen	23	$mg\ kg\ Soil^{-1}$
Available phosphorus	6.9	$g\ kg^{-1}\ soil$
Available Potassium	123	
Sand	430	
Silt	319	
Clay	251	Loam
Soil texture		

2.1.3. Experiment Factor:

Factor One: Four levels of irrigation water salinity:

- 1- Saline water at $EC=2\ ds\ m^{-1}$
- 2- Diluted brackish water at $EC=4\ ds\ m^{-1}$.
- 3- Diluted brackish water at $EC=6\ ds\ m^{-1}$.
- 4- Diluted brackish water at $EC=8\ ds\ m^{-1}$.

Factor Two: Potassium fertilizer level:

- 1- Without fertilization, denoted as K_1 .
- 2- fertilization at $120\ kg\ K\ ha^{-1}$ in the form of potassium sulphate K% 40.43, denoted as K_2 .

Factor Three: Three concentrations of salicylic acid sprayed on the plant:

- 1- No spraying, denoted as S_1 .
- 2- Spraying with salicylic acid, at a concentration of $(150\ mg\ L^{-1})$, denoted as S_2 .
- 2- Spraying with salicylic acid, at a concentration of $(300\ mg\ L^{-1})$, denoted as S_3 .

2.1.4. Measurement of some obtained indicators

Plant measurements were taken on 1/5/2026 as an average of five plants per experimental unit as follows::

- 1-Sodium concentration in the grains.
 - 2-Potassium concentration in the grains.
 - 3-Amount of sodium absorbed in the grains (mg m^{-2}).
 - 4 - Proline amino acid concentration in the grains
- ysical properties of the soil before planting.

3. RESULTS AND DISCUSSION

3.1. RESULTS

3.1.1.Sodium concentration in grains (micrograms per gram of dry matter)

The results shown in Table (2) indicate that irrigation water salinity levels have a significant effect on sodium concentration in grains. The salinity level of 8 dS m^{-1} recorded the highest rate of $1809 \text{ micrograms g}^{-1}$ of dry matter, followed by the 6 dS m^{-1} salinity level which gave $1482 \text{ micrograms g}^{-1}$ of dry matter, then the 4 dS m^{-1} salinity level with an average of $1142 \text{ micrograms g}^{-1}$ of dry matter, while the 2 dS m^{-1} salinity level recorded the lowest rate of $821 \text{ micrograms g}^{-1}$ of dry matter. This increase is attributed to the fact that higher salinity leads to increased sodium loading in the xylem with a decline in its retrieval efficiency in the roots under severe stress. Especially when the efficiency of the organised sodium transport pathways connected to its reduced transfer to aerial parts declines. As stress continues into the reproductive stages, the likelihood of some sodium reaching the tissues associated with grain filling increases, and the reduced dry matter accumulation in the grain under salinity may raise its sodium concentration due to weakened dilution; hence, its concentration gradually increased with higher salinity levels in this study. [4]. The results shown in Table (1) indicated that salicylic acid had a significant effect on the sodium concentration in grains, with the control treatment recording the highest level of $1508 \text{ micrograms g}^{-1}$ dry matter, followed by the 150 mg L^{-1} concentration which gave $1293 \text{ micrograms g}^{-1}$ dry matter, while the 300 mg L^{-1} concentration resulted in the lowest level of $1138 \text{ micrograms g}^{-1}$ dry matter. This decrease is attributed to the fact that salicylic acid does not merely affect the general

activation of plant responses but also contributes to the reorganisation of protective pathways associated with the ascorbate–glutathione cycle and the phenylpropanoid pathway, along with enhancing lignin formation and improving tissue barrier structure, thereby maintaining cell efficiency under saline stress. This may reduce uncontrolled ion movement and decrease sodium transfer to reproductive organs, hence the sodium concentration in grains decreased with increasing salicylic acid levels, with the 300 mg L⁻¹ concentration being the most effective under the conditions of this study. [5]. As shown in the results presented in Table (1), the addition of potassium sulphate has a significant effect on sodium concentration in the grains. The non-addition treatment k₁ recorded the highest rate of 1325 µg g⁻¹ dry matter, while the addition treatment k₂ gave the lowest rate of 1302 µg g⁻¹ dry matter. This decrease is attributed to the fact that the availability of potassium helps maintain membrane polarization and reduces severe K⁺ loss from root cells under oxidative stress, thereby keeping ion selectivity more efficient and weakening sodium translocation to the upper parts. Furthermore, salt tolerance in wheat is associated with the plant's ability to combine potassium retention and regulation of sodium retrieval from the long-distance transport stream. Therefore, potassium addition improves ionic regulation efficiency and reduces sodium accumulation in the grains, which was reflected in this study by the lower concentration under the addition treatment compared to the non-addition one. [5]. The interaction treatments between irrigation water salinity levels and salicylic acid shown in Table (1) revealed no significant differences between the treatments, although the highest numerical value for sodium concentration in the grains was observed in the treatment with irrigation using water with a salinity of 8 dS m⁻¹ combined with 0 mg L⁻¹ salicylic acid, reaching 2004 µg g⁻¹ dry matter, while the lowest numerical value was observed in the treatment with irrigation using water with a salinity of 2 dS m⁻¹ combined with 300 mg L⁻¹ salicylic acid, reaching 647 µg g⁻¹ dry matter. As shown in Table (1), the interaction between irrigation water salinity levels and potassium sulphate did not have a significant effect on the sodium concentration in the grains, although the highest numerical value appeared with irrigation using water of 8 dS m⁻¹ salinity without potassium addition (k₁), reaching 1820 µg g⁻¹ dry matter, while the lowest numerical value appeared with irrigation using water of 2 dS

m^{-1} salinity with potassium addition (k_2), reaching $810 \mu\text{g g}^{-1}$ dry matter. The results in Table (1), also showed that the interaction, between potassium sulphate and salicylic acid caused significant differences among treatments, with the treatment of no potassium addition (k_1) with 0 mg L^{-1} salicylic acid recording the highest sodium concentration in the grains at $1538 \mu\text{g g}^{-1}$ dry matter, while the treatment of no potassium addition (k_1) with 300 mg L^{-1} salicylic acid recorded the lowest value at $1118 \mu\text{g g}^{-1}$ dry matter. The three-way interaction between irrigation water salinity levels, potassium sulphate and salicylic acid did not show a significant effect on sodium concentration in the grains. However, the highest numerical value was observed under irrigation with water of 8 dS m^{-1} salinity with no potassium addition (k_1) and 0 mg L^{-1} salicylic acid, reaching $2034 \mu\text{g g}^{-1}$ dry matter, while the lowest numerical value appeared under irrigation with water of 2 dS m^{-1} salinity with no potassium addition (k_1) and 300 mg L^{-1} salicylic acid, reaching $627 \mu\text{g g}^{-1}$ dry matter.

Table (2) Effect of salinity levels, salicylic acid, and potassium fertilizer on sodium concentration in grains ($\mu\text{g g}^{-1}$ dry matter)

E*K	s3	s2	s1	K	E
833	627	827	1046	k1	e1
810	667	777	987	k2	
1153	947	1147	1367	k1	e2
1130	987	1097	1307	k2	
1493	1287	1487	1707	k1	e3
1470	1327	1437	1647	k2	
1820	1614	1814	2034	k1	e4
1797	1654	1764	1974	k2	
ns	Ns			LSD5%	
men E	E*S			E	
821	647	802	1016	e1	
1142	967	1122	1337	e2	
1482	1307	1462	1677	e3	
1809	1634	1789	2004	e4	
1.61	Ns			LSD5%	
men k	K*S			K	
1325	1118	1318	1538	k1	
1302	1158	1268	1478	k2	
1.14	1.97			LSD5%	
	1138	1293	1508	men's S	

	1.39	LSD5%
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3.1.2. Potassium concentration in grains (micrograms per gram of dry matter)

The results shown in Table (3) indicate that the levels of irrigation water salinity have a significant effect on the potassium concentration in the grains, with 2 dS m⁻¹ salinity level giving the highest rate of 2537 µg g⁻¹ dry matter, followed by a gradual decrease with increasing salinity levels to reach 2468, 2383, and 2281 µg g⁻¹ dry matter at salinity levels of 4, 6, and 8 dS m⁻¹, respectively. This decrease may be attributed to the fact that potassium accumulation in the grains does not rely solely on root uptake, but also on the efficiency of cellular K⁺ retention in leaf tissues, particularly the flag leaf, and on the efficiency of its remobilisation and phloem transport during the grain filling stage. With increased salinity, membrane potential disruption occurs, and cytoplasmic K⁺ loss increases due to the activation of its leakage pathways under ionic and oxidative stress, alongside sodium dominating the uptake and transport environment. This reduces the plant's ability to retain potassium within the active cytosolic pool and limits its continuous transport from source organs to the grains, thus decreasing its concentration in the grains as salinity rises [6]. As for the results shown in Table (2), they indicated that salicylic acid had a significant effect on the potassium concentration in the grains, with the 300 mg L⁻¹ concentration giving the highest value of 2543 µg g⁻¹ dry matter, followed by the 150 mg L⁻¹ concentration which gave 2448 µg g⁻¹ dry matter, while the control treatment of 0 mg L⁻¹ recorded the lowest value of 2261 µg g⁻¹ dry matter. This increase is attributed to salicylic acid acting as an integrative regulator of the plant's response, as its effect is not limited to activating antioxidants, but it also readjusts the redox state and components of the ascorbate–glutathione cycle, reduces membrane damage and electrolyte leakage, while enhancing cell wall thickening through activation of the phenylpropanoid pathway and increasing relative lignification. These modifications reduce uncontrolled K⁺ loss from the cells and maintain continuous photosynthetic performance of source leaves during filling, thereby improving the efficiency of potassium translocation to the grains. Moreover, the improved grain characteristics and growth under saline conditions following salicylic treatment indicate that the plant has become more capable of directing its mineral and photosynthetic resources towards reproductive organs, which is why the concentration exceeded 300 mg L⁻¹ in this study. [7]. As shown by the results in Table (2), the addition of potassium sulphate had a significant effect on the potassium concentration in the grains, with the K₂ addition treatment giving the highest rate of 2589 µg g⁻¹ dry matter compared to the no-addition treatment K₁, which recorded 2246 µg g⁻¹ dry matter. This superiority may be attributed to the fact that potassium fertilisation not only increases the availability of the element in the rhizosphere but also supports its utilisation efficiency within the plant during critical stages of yield formation, particularly during grain filling. Potassium is an element closely associated with regulating phloem transport, maintaining leaf metabolic activity, delaying functional senescence, and improving the translocation of photosynthetic

products from source to sink. When plant potassium nutrition is adequate, the upper green leaf remains more capable of functioning as an active source. The transport of sugars and their accompanying ions towards the grain becomes more efficient, leading to an increased accumulation of potassium in the grains. This becomes particularly important under salinity, as the availability of K^+ supports tissue tolerance traits and mitigates the damaging effects of Na^+/K^+ imbalance, which explains the higher potassium concentration in grains with supplementation compared to without supplementation. [8]+[4]. Table (2) indicated significant differences between the irrigation water salinity level and salicylic acid interactions. The highest grain potassium concentration ($2655 \mu g g^{-1}$ dry matter) was in the irrigation treatments with water salinity ($2 dS m^{-1}$) and salicylic ($300 mg L^{-1}$) concentrations; while the lowest grain potassium concentration ($2122 \mu g g^{-1}$ dry matter) was in the irrigation treatments at water salinity level ($8 dS m^{-1}$) and salicylic level ($0 mg L^{-1}$). This was also found on the results (Table 1). Potassium concentrations in the grain differed significantly among treatments with irrigation of water salinity $2 dS m^{-1}$ in the presence of potassium application k2 yielding the highest sample potassium concentration of $2705 \mu g g^{-1}$ dry matter and irrigation of water salinity $8 dS m^{-1}$ in the absence of potassium application k1 yielding the lowest sample potassium concentration of $2100 \mu g g^{-1}$ dry matter. The interaction effect between potassium sulphate and salicylic acid did not result in any significant difference among the treatments for the result presented in Table (1), with the highest concentration of potassium in the grain of $2688 \mu g g^{-1}$ DM obtained from the k2 and $300 mg L^{-1}$ salicylic acid treatments, while the lowest concentration of $2058 \mu g g^{-1}$ DM was achieved with no potassium application k1 and $0 mg L^{-1}$ salicylic acid treatments. As for the triple interaction between irrigation water salinity levels, potassium sulphate and salicylic acid, the numerical values showed that the highest value occurred with irrigation treated with water of $2 dS m^{-1}$ salinity with potassium addition k2 and $300 mg L^{-1}$ salicylic acid, reaching $2785 \mu g g^{-1}$ dry matter, while the lowest value appeared with irrigation treated with water of $8 dS m^{-1}$ salinity with no potassium addition k1 and $0 mg L^{-1}$ salicylic acid, amounting to $1910 \mu g g^{-1}$ dry matter.

Table (3) Effect of salinity levels, salicylic acid, and potassium fertiliser on potassium concentration in grains (micrograms per gram of dry matter)

E*K	s3	s2	s1	K	E
2370	2525	2390	2195	k1	e1
2705	2785	2735	2595	k2	
2303	2450	2350	2110	k1	e2
2633	2740	2660	2500	k2	
2211	2365	2250	2020	k1	e3
2555	2660	2580	2425	k2	
2100	2250	2140	1910	k1	e4
2463	2570	2485	2335	k2	

3.1.3.

1.62	2.81			LSD5%
men E	E*S			E
2537	2655	2562	2395	e1
2468	2595	2505	2305	e2
2383	2512.5	2415	2222	e3
2281	2410	2312	2122	e4
1.14	1.99			LSD5%
men k	K*S			K
2246	2397	2282	2058	k1
2589	2688	2615	2463	k2
0.81	1.40			LSD5%
	2543	2448	2261	men S
	0.99			LSD5%

The

amount of sodium absorbed in the grains (mg m⁻²)

The results shown in Table (4) indicate that irrigation water salinity levels have a significant effect on the amount of sodium absorbed in the grains, with a salinity level of 8 dS m⁻¹ recording the highest rate of 596 mg m⁻², followed by the 6 dS m⁻¹ level at 508 mg m⁻², then the 4 dS m⁻¹ level at an average of 418 mg m⁻², while the 2 dS m⁻¹ level recorded the lowest rate of 315 mg m⁻². This increase may be attributed to the fact that this trait does not represent only sodium concentration but also the final sodium load that ends up in the grains per unit area, thus it is influenced by the net absorption, transport, and redistribution during the filling stage. Under high salinity, +Na presence in the root zone increases, putting more pressure on ion regulation systems responsible for its exclusion or retrieval from the long-distance transport stream, such as HKT, SOS, and NHX systems. When the efficiency of these systems falls short of coping with the increasing salt load, the fraction of sodium that escapes exclusion rises and reaches the aerial organs and then the reproductive sinks. It appears that the considerable increase in sodium concentration within the grain had a greater impact than the decline in yield; thus, the amount absorbed increased with salinity, indicating that the intensity of ionic loading outweighed the effect of reduced grain mass at higher salinity levels. This explanation aligns with recent studies showing that salinity in wheat enhances sodium accumulation in grains while reducing potassium and that tolerance efficiency is linked to the plant's ability to regulate sodium transport and recovery before it reaches sensitive parts [9]. The results shown in Table (3) indicated that salicylic acid had a significant effect on the amount of sodium absorbed by the grains, with the concentration of 150 mg L⁻¹ yielding the highest rate of 535 mg m⁻², followed by the concentration of 0 mg L⁻¹ which gave 451 mg m⁻², while the concentration of 300 mg L⁻¹ produced the lowest rate of 392.5 mg m⁻². This variation may be due to the fact that this trait, being a cumulative trait, is determined by the combined interaction of two factors: the sodium concentration in the grain and the amount of dry matter. Therefore, the superior performance at the medium salicylic concentration does not necessarily mean an increase in ionic toxicity, but is likely due to an improved plant efficiency in yield formation and an increased filling strength of the grain

during the filling stage. The total amount reaching the grains per square metre increased, even with salicylic acid continuing to regulate salt damage. At the higher concentration of 300 mg L⁻¹, its effect tended to reduce the passage of sodium into the grains and decrease its final accumulation in them, or its stimulatory response to yield was no longer as effective as at the medium dose, thus reducing the amount absorbed [10]. The results shown in Table (3) indicated that the addition of potassium sulphate had a significant effect on the amount of sodium absorbed by the grains, as the k₂ addition treatment recorded the highest rate of 495 mg m⁻² compared to the k₁ non-addition treatment which registered 423 mg m⁻². This increase may be attributed to the fact that the amount absorbed represents the total sodium stock in the grains per unit area, and is not solely an indicator of ionic imbalance. Therefore, the increase in this trait with potassium addition can be explained by potassium enhancing plant efficiency after flowering, particularly maintaining leaf functional activity, sink efficiency, and grain filling. The final grain mass increased, and accordingly the total sodium load accumulated in the grains per square metre may rise even if its relative concentration within the grain does not increase. That is, what increased was the total accumulation associated with grain sink expansion, not necessarily the intensity of ionic toxicity within the tissues. This is supported by the fact that potassium addition raised the yield [11]. The binary interaction between irrigation water salinity levels and salicylic acid shown in Table (3) indicated significant differences between the treatments, as irrigation with water of 8 dS m⁻¹ salinity combined with 150 mg L⁻¹ salicylic acid gave the highest sodium uptake in the grains at 675 mg m⁻², whereas irrigation with water of 2 dS m⁻¹ salinity combined with 300 mg L⁻¹ salicylic acid gave the lowest rate at 260 mg m⁻². As shown by the results in Table (12) and Appendix (12), the interaction between irrigation water salinity levels and potassium sulphate produced significant differences among treatments, with the irrigation treatment using water of 8 dS m⁻¹ salinity combined with potassium addition k₂ yielding the highest sodium uptake in grains at 673 mg m⁻², whereas the irrigation treatment with water of 2 dS m⁻¹ salinity with potassium addition k₂ resulted in the lowest uptake at 303 mg m⁻². The results from the Table (3) showed that all levels of interactions between potassium sulphate and salicylic acid caused significant differences among the treatments, and the highest sodium uptake in grains was found with treatment (k₂) without salicylic acid while the lowest uptake was recorded with treatment (k₁) in combination with 300 mg L⁻¹ salicylic acid at 565 and 362.5 mg m⁻², respectively. The interaction between irrigation water salinity level, potassium sulphur and salicylic acid gave significant effect between treatments, irrigation using water of 8 dS m⁻¹ salinity with potassium sulphur k₂ showed the highest sodium uptake in grains (730 mg m⁻²) and irrigation using water of 2 dS m⁻¹ salinity with potassium sulphur k₂ and salicylic acid (300 mg L⁻¹ showed) the lowest sodium uptake in grains (250 mg m⁻²).

Table (4) Effect of salinity levels, salicylic acid and potassium fertilizer on the amount of sodium absorbed in grains (mg m⁻²)

E*K	s3	s2	s1	K	E
326	270	390	320	k1	e1
303	250	360	300	k2	
393	330	470	380	k1	e2

443	360	520	450	k2	
453	390	540	430	k1	e3
563	480	650	560	k2	
520	460	620	480	k1	e4
673	600	730	690	k2	
5.70	9.88			LSD5%	
men E	E*S			E	
315	260	375	310	e1	
418	345	495	415	e2	
508	435	595	495	e3	
596	530	675	585	e4	
4.03	6.99			LSD5%	
men k	K*S			K	
423	362.5	505	402	k1	
495	422.5	565	500	k2	
2.85	4.94			LSD5%	
	392.5	535	451	men S	
	3.49			LSD5%	

3.1.4. Concentration of the amino acid proline in the grains (micrograms per gram of dry matter).

As can be seen from the data presented in Table (5), significant effect of the amount of irrigation water salinity on the concentration of the amino acid proline in the grains. The salinity level of 8 dS m⁻¹ recorded the highest level of 81.74 µg g⁻¹ dry matter, followed by salinity level of 6 dS m⁻¹ which gave 58.66 µg g⁻¹ dry matter, then salinity level of 4 dS m⁻¹ which gave an average rate or value of 36.83 µg g⁻¹ dry matter, while salinity level of 2 dS m⁻¹ recorded the lowest rate of 16.65 µg g⁻¹ dry matter. This increase could be due in part to the fact that salt stress during the later stages of growth causes not only osmotic and ionic stress, but also rebalances the carbon–nitrogen ratio in the plant, enhancing nitrogen recycling, breaking down some protein compounds, and redirecting part of the nitrogen in the form of free amino acids towards the sink organs. This includes the grains. In such cases, proline becomes part of the free amino acids that accumulate in the grain under salt stress, particularly with the stimulation of its synthesis pathway from glutamate and the reduced incorporation into storage proteins under stress conditions. Therefore, the increase in proline in the grains here not only indicates a general defensive response but also reflects a shift in nitrogen metabolism and grain filling under salinity, which explains the gradual increase with rising stress intensity [11]. As seen in Table (4) the treatments with salicylic acid significantly affected proline concentration in the grains, and it was found that the higher concentration of salicylic acid (300 mg l⁻¹) had the highest value of 60.42 micrograms. The 1 mg d⁻¹ dry matter yielded 48.72 µg mg⁻¹ dry matter with the concentration of 150 mg d⁻¹ dry matter yielded 36.27 µg mg⁻¹ dry matter, the lowest value was recorded for control (0 mg d⁻¹ dry

matter) which yielded $36.27 \mu\text{g mg}^{-1}$ dry matter. This increase may be due to salicylic acid acting as a high-level regulator that readjusts the plant's salt stress response at both the genetic and physiological levels, contributing to osmotic balance and reactive oxygen species management, and mitigating disruptions in metabolic activities associated with the filling phase. Consequently, salicylic acid-treated plants better maintain the vitality of essential tissues and the continuity of assimilate and reduced nitrogen flow to the grains, enhancing adaptive soluble compounds, including proline. Moreover, salicylic acid may direct the response towards increased proline synthesis or maintain it in its free form within the grain as part of the metabolic preparation for stress tolerance, hence the higher concentration outperforms [10]. As shown in Table (4), the addition of potassium sulphate had a significant effect on the proline concentration in the grains, with the K_2 treatment giving the highest rate of $49.54 \mu\text{g g}^{-1}$ dry matter compared to the non-addition K_1 treatment which recorded $47.40 \mu\text{g g}^{-1}$ dry matter. This superiority may be attributed to potassium maintaining the efficiency of the upper leaves and delaying the deterioration of their functional activity, supporting the translocation of assimilates and mobile nitrogen through the phloem, and increasing the accumulation of K and N in the plant during the grain-filling stage. When the filling efficiency improves and the grain's assimilate uptake capacity increases, the amount of amino acids reaching the endosperm also increases. This may manifest as a slight increase in certain free amino acids, including proline. Accordingly, the rise in proline under potassium treatment reflects improved nitrogen remobilisation and sink strength, meaning that the grain has become more capable of accumulating soluble nitrogen compounds during development. This explains why the trend of proline in grains sometimes differs from that in vegetative tissues, as its measurement in grains represents the cumulative effect of filling and deposition rather than the intensity of instantaneous stress alone. [12]. As shown in the results of both-way interaction between irrigation water salinity level and salicylic acid (Table 4) significantly different results were obtained, where irrigation with water of 8 dS m^{-1} salinity with 300 mg L^{-1} salicylic acid recorded the highest concentration of proline in grains with a value of $92.73 \mu\text{g g}^{-1}$ dry matter, whereas irrigation with water of 2 dS m^{-1} salinity and 0 mg L^{-1} salicylic acid recorded the lowest concentration of proline in grains with a value of $6.60 \mu\text{g g}^{-1}$ dry matter. The results in Table (4) also show that the two-way interaction between irrigation water salinity levels and potassium sulphate produced significant differences between treatments, with irrigation using 8 dS m^{-1} salinity water with no potassium addition k_1 giving the highest proline concentration in grains at $82.15 \mu\text{g g}^{-1}$ dry matter, while irrigation with 2 dS m^{-1} salinity water and no potassium addition k_1 recorded the lowest rate at $14.13 \mu\text{g g}^{-1}$ dry matter. The results in Table (4) also indicate that the two-way interaction between potassium sulphate and salicylic acid caused significant differences between treatments. The treatment of potassium addition K_2 with 300 mg L^{-1} salicylic acid recorded the highest proline concentration in the grains at $62.50 \mu\text{g g}^{-1}$ dry matter, while the treatment of potassium addition K_2 with 0 mg L^{-1} salicylic acid recorded the lowest value at $36.00 \mu\text{g g}^{-1}$ dry matter. Significant differences between treatments were observed for irrigation water

salinity level, potassium sulphate and salicylic acid in relation to each other. The greatest concentration of proline in the grain was produced by the water of 8 dS m⁻¹ salinity and no addition of potassium (K1) while the lowest concentration was in the grain of water irrigated with 2 dS m⁻¹ salinity and no potassium addition (K1).

Table (5) Effect of salinity levels, salicylic acid and potassium fertilizer on proline amino acid concentration in grains (micrograms per gram of dry matter).

E*K	s3	s2	s1	K	E
14.13	24.4	12.8	5.21	k1	e1
19.16	31	18.5	8	k2	
37.50	48	38.5	26	k1	e2
36.16	54	33.5	21	k2	
55.83	66.5	56	45	k1	e3
61.50	74	60.5	50	k2	
82.15	94.47	82	70	k1	e4
81.33	91	88	65	k2	
0.49	0.86			LSD5%	
men E	E*S			E	
16.65	27.70	15.65	6.60	e1	
36.83	51.00	36.00	23.50	e2	
58.66	70.25	58.25	47.50	e3	
81.74	92.735	85.00	67.50	e4	
0.35	0.60			LSD5%	
men k	K*S			K	
47.40	58.34	47.32	36.55	k1	
49.54	62.50	50.12	36	k2	
0.24	0.43			LSD5%	
	60.42	48.72	36.27	men S	
	0.30			LSD5%	

3.2.Discussion

The results in Table (1) showed that increasing, irrigation water salinity led to a rise in sodium concentration in the grains, while both salicylic acid and potassium fertilisation contributed to reducing sodium accumulation and improving ionic balance within the plant. This is attributed to the role of salicylic acid and potassium in reducing sodium transport and maintaining cell membrane integrity, which is consistent with the findings of [4,13]. As for the results in Table (2), they indicated that increased salinity caused a decrease in potassium

concentration in the grains due to competition between sodium and potassium ions, whereas spraying with salicylic acid and adding potassium fertiliser increased potassium concentration and improved absorption and transport efficiency within the plant. These results aligned with the observations of and [6, 8]. As shown by the results in Table (3), the amount of sodium absorbed in the grains increased with higher salinity levels due to the accumulation of sodium within the plant, while salicylic acid and potassium treatments helped reduce the negative effects of salt stress and improve growth and yield efficiency, in agreement with the findings of [9,11]. Meanwhile, the results in Table 4 indicated that the proline amino acid concentration increased with higher salinity levels, as it is one of the regulatory compounds that accumulate within the plant to maintain osmotic balance and reduce stress damage, and both salicylic acid and potassium fertilisation led to increased proline accumulation and enhanced plant stress tolerance, consistent with the observations of [14,15].

4.CONCLUSIONS

1-The increase in irrigation water salinity levels led to higher accumulation of sodium and proline in the grains and a decrease in potassium concentration, negatively affecting growth efficiency and productivity.

2-Potassium fertilisation contributes to improving ionic balance within the plant by reducing the harmful effects of sodium and increasing the potassium concentration in the grains.

3-Salicylic acid has shown an important role in enhancing wheat plant tolerance to salt stress by improving physiological traits and reducing the damage caused by salinity.

4-A concentration of 300 mg L⁻¹ of salicylic acid achieved the best results, in most of the studied, traits compared to the control treatment.

5-The interaction, between potassium fertilisation and salicylic acid helped improve wheat plant response under salt stress conditions compared to using each treatment individually.

6-Transactions with low salinity combined with potassium addition and salicylic acid spraying recorded the highest values in growth traits and yield.

7-Potassium fertilisation combined with salicylic acid spraying can be used as an effective management strategy to reduce the impact of irrigation water salinity and improve wheat productivity in salt-affected soils.

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