Effect of potassium fertilization and foliar application of ascorbic acid and citric acid on wheat growth under salt stress conditions

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Abstract

The aim of this study was to investigate the combined effects of potassium fertilizer and foliar spray of a mixture of ascorbic acid and citric acid on some vegetative growth trait of wheat (Abu-Ghraib variety) under different irrigation water salinities. The experiment adopted a factorial design in CRD with three factors: two potassium added levels (0 and 100 kg ha^{-1}), three ascorbic acid&citric acid levels (0, 200, and 400 mgL^{-1}), and two irrigation salinity levels (1 and 3 dS m^{-1}). The results showed that both treatments (100 kg ha^{-1} of potassium fertilizer and 400 m L^{-1} of foliar spray of a mixture acid) significantly increased the investigated vegetative growth variables (plant height, leaf number, leaf area, and dry weight) when applied alone compared with the control. The most significant effect was observed under the interaction of the highest potassium application and the highest ascorbic acid&citric acid concentration, which was superior to the single treatment. More importantly, the three-way interaction showed a synergistic effect in alleviating salt stress. Under high salinity (1 dS m^{-1}), plants treated with 100 kg K ha^{-1} and 400 mg L^{-1} ascorbic acid showed the highest values for all growth parameters.

Keywords: *Triticum aestivum* L. ,Potassium, ascorbic acid and citric acid , Salinity Stress ,Foliar Spraying.

Introduction

Bread wheat [Triticum aestivum L.] is a mainstay of global food security and the most strategically important crop, Global wheat production is approximately 842 million tons annually. Locally, Iraq's wheat production is estimated at 6 million tons per year. Regarding soil, about 10.7% of the world's land is affected by salinity, while in Iraq, this percentage exceeds 50% of arable land, particularly in the central and southern regions. [1]. Despite the current security of wheat supply, the global gap between supply and

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demand is widening due to the continued growth of the world population. At the beginning of this century, the global population exceeded 6 billion, with more than half of the growth occurring in developing countries [2]. As a result, many countries have implemented agricultural and economic policies to increase domestic production and minimize dependence on imports in order to achieve self-sufficiency [3]. Iraq is a good example, with its huge agricultural potential, fertile soil, abundant water resources and a suitable climate. Iraq is a major center for wheat domestication, production is caused by a variety of interrelated factors, including the lack of integrated crop management and increased environmental stress, especially soil salinization, high salinity in irrigation water, and drought [4]. From a physiological perspective, salt stress is widely recognized as one of the most significant challenges to plant productivity in arid and Semi-arid areas [5] One of the most important methods used to reduce the effects of salinity on plants is the use of nutrients necessary for the plant and soil fertilization with nitrogen, phosphorus and potassium.. It maintains cellular turgor pressure through osmotic regulation and stomatal movement regulation, thereby achieving efficient water use and reducing transpiration under drought and salinity conditions, which is an essential function of plants[6].This Sufficient potassium in the rhizosphere reduces the net uptake of sodium by plant cells, thereby reducing sodium accumulation in the plant and reducing ion toxicity. [7].

This Potassium supplementation, exogenous antioxidants, including ascorbic acid (vitamin C), have also been shown to be effective in enhancing the growth defense system of certain crops. Ascorbic acid is a low molecular weight substance that is one of the most abundant non-enzymatic antioxidants in plants. It is an antioxidant that scavenge reactive oxygen species (ROS) and releases some hydrogen, acting as a weak link in the ascorbate-glutathione cycle, which is the main line of defense against oxidative stress [8, 9]. Its antioxidant activity, vitamin C is involved in many important physiological processes, including cell division and growth, cell wall biosynthesis, delaying leaf senescence, and stimulating lateral bud growth [10, 11]. This , citric acid is a key organic acid in the Krebs cycle and is essential for energy metabolism and reducing power (ATP and NADPH) for various life processes. It is responsible for maintaining the acid-base balance within the cell, thereby creating a favorable biochemical environment for enzymatic processes and metabolism.

Although many scientific studies have investigated the effects of potassium and ascorbic acid separately, data on their combined

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effects are scarce, especially when ascorbic acid is used in combination with citric acid. A more comprehensive understanding of these interactions could support the development of systematic, integrated agronomic approaches to improve wheat yield under stress conditions. Therefore, the aim of this study was to investigate the effects of soil potassium application and foliar application of a mixture of ascorbic acid and citric acid and their interactions on some vegetative growth parameters of wheat (Abu Ghraib variety) under different irrigation water salinities. This study aimed to determine the optimal treatment to mitigate the effects of salt stress and promote plant growth.

phosphorus on vegetative growth, yield and quality of two grapevine cultivars (*Vitis vinifera* L.) [4].

Material and Methods

2.1 Experimental Site and Soil Physicochemical Analysis

This study was conducted during the 2023-2024 winter growing season in plastic pots in the Nile area, Babil Governorate, Iraq. Before planting, a composite soil sample was taken from the experimental soil, air-dried, ground, and screened using a 2 mm sieve. Some physical and chemical properties of the soil were determined according to the methods described in Page et al. [12], as shown in Table (1)**.**

2.2 Experimental Design and Treatments

The experiment was designed as a factorial trial (2 × 3 × 2) based on a Completely Randomized Design (CRD), with three replications. It included the following three factors:

1. Soil Application of Potassium Fertilizer (A):

A_1: Control treatment (no potassium added).

A_2: Potassium application at a rate of 100 kg K · ha^{-1} as a potassium sulphate. Fertilizer was applied in three equal doses: The first at emergence, the second at stem elongation and the third on the early flowering.

2. Foliar Spray with Ascorbic acid &citric acid (C):

C0 = Control, C1 = 200mg L^{-1} ,C2 = 400mg L^{-1} Foliar spray treatments were applied at two growth stages: the first when the plant had four true leaves, and the second when the plant had eight leaves .

3. Salinity Levels

B_1: irrigation water (1 $dS \cdot m^{-1}$).

B_2: irrigation water (3 $dS \cdot m^{-1}$).

2.3. Agricultural Operations and Experiment Management

Wheat seeds ("Abu Ghraib" variety) were sown in 5 kg plastic pots filled with premixed soil on November 26, 2023. Five seeds were planted per pot. 25 days after sowing , seedlings were carefully thinned out so that only one uniformly grown plant remained per pot, thus ensuring

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equal competitive conditions. Irrigation was carried out as needed using water prepared according to the salinity specified for each treatment(Flowering complete).

2.4. Preparation and Application of Foliar Treatments (Ascorbic acid and citric acid)

solutions were prepared by dissolving ascorbic acid and citric acid in a 2:1 weight ratio in distilled water to obtain the corresponding final concentrations (200 and 400 mg L^{-1}). All spray solutions (including the control solution) were supplemented with a nonionic surfactant (e.g., 0.1% Tween 20) to promote wetting of the shoot system and reduce the surface tension of the droplets. Applications were made in the early morning using a 5-liter hand sprayer to reduce evaporative losses in the high temperature.

2.5 Measurements and Statistical Analysis

At the end of the vegetative growth phase, morphological and developmental characteristics were measured. The collected data were using the statistical analysis program Genastat. Analysis of variance (ANOVA) was used to determine the significance of the effects of factors and their interactions, and means of treatments were compared using the least significant difference (LSD) test at the 0.05 probability level [13].

Results and Discussion

Shoot length (cm)

3.1 Plant height (cm)

The results of ANOVA (Table 2) showed that foliar spraying of ascorbic acid, potassium fertilization, salinity of irrigation water, and their mutual and triangular interactions had significant effects on plant height ($P \leq 0.05$). Foliar spraying of 400 mg·L-1 ascorbic acid and citric acid significantly increased plant height, reaching 55.08 and 46.2 cm, respectively, in the control treatment (spraying with distilled water). The above treatment effects may be due to the physiological effects of ascorbic acid and citric acid, which is the main component of ascorbic acid. Cell division and growth are essential for stem elongation and plant height [14], and ascorbic acid is required to achieve this goal. In addition, it can also act as a powerful antioxidant to scavenge reactive oxygen species (ROS) produced in large quantities under salt stress, protect cell membranes and enzyme systems from oxidative damage, and ensure uninterrupted plant growth [15]. The interaction between potassium fertilizer (100 kg ha^{-1}) and ascorbic acid & citric acid spray treatment (400 mg l^{-1}) showed statistically significant dominance, with the highest mean plant height (63.4 cm). This suggests a synergistic effect between the two plant species. Potassium regulates the physiological balance of cellular water balance and turgor pressure, thereby creating optimal conditions for ascorbic acid to promote cell growth.

The strongest effect was observed in the three-factor interaction studied. Treatment ($A_2B_1C_2$) - a combination of 100 kg potassium and 400 mg L^{-1} ascorbic&citric acid per ha at the highest salinity (1 dS m^{-1}) - achieved the maximum plant height of 67.7 cm. This finding is particularly important because it suggests that the combined application of potassium and ascorbic&citric acid not only alleviated the inhibitory effect of salinity but also stimulated growth to a greater extent than all other treatments, even under milder stress conditions. These results are consistent with those of [16], who highlighted the role of antioxidants and potassium in promoting plant growth under stress. [17, 18, 19].

3.2 Number of Leaves

The results (Table 3) showed that ascorbic acid &citric acid , potassium, irrigation water salinity and their interaction had significant effects on the average number of leaves per plant ($P \leq 0.05$). Spraying with ascorbic acid& citric at a concentration of control significantly increased the number of leaves. This effect was attributed to the role of ascorbic acid in delaying leaf senescence accelerated by salt stress and its role in stimulating the division of meristematic cells responsible for new leaf formation [14].

The interaction of adding 100 kg ha^{-1} potassium and spraying 400 mgL^{-1} ascorbic acid & citric acid resulted in the highest leaf number (13.75 leaves per plant). This confirms the complementary mode of action between the two: potassium improves the ability of plants to retain leaves by improving water balance, while ascorbic acid protects plants from oxidative damage.

In the triple interaction, the highest number of leaves (12.6 per plant) was measured under high salinity (1 dS m^{-2}) with 100 kg K h^{-1} fertilizer per hectare and 400 mg L^{-1} ascorbic acid &citric per liter spray ($A_2B_1C_2$). This means that, despite the adverse conditions, this combined treatment allowed the plants to achieve a high leaf production, resulting in a vigorous shoot system. These results are in line with several studies showing that not only optimal K supply, but also exogenous application of antioxidants in combination with stress can improve plant growth. [20, 21, 22].

3.3 Leaf Area (cm² plant^{-1})

All investigated factors and their interactions significantly affected leaf area ($P \leq 0.05$) (Table 4). Foliar application of 400 mg L^{-1} ascorbic &citric acid resulted in the largest leaf area (183.68 cm² $plant^{-1}$). Leaf area is a direct result of cell division and cell growth, both of which are stimulated by ascorbic acid. In addition, protection of chlorophyll from oxidative degradation helps maintain active leaves with a larger surface area [23, 24]. Potassium

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addition in turn resulted in a significant increase in leaf area (177.03 cm² $plant^{-1}$), consistent with its key role in maintaining turgor pressure required for cell growth and leaf development [25]. The interaction effect was even more pronounced. The mutualistic effect between potassium (100 kg K ha^{-1}) and ascorbic &citric acid (400 mg L^{-1}) produced the largest leaf area (192.75 cm² $plant^{-1}$). This advantage was further enhanced by the triple interaction, with the treatment group ($A_2B_1C_2$) achieving a record increase in leaf area per plant of 199.1 cm² $plant^{-1}$ under high salt stress. Leaf area increases with plant height table (2) and the plant's tolerance to salinity as a result of adding ascorbic acid and citric acid, which provides a defensive means for the plant to tolerate salinity. [26] and [27], which showed that potassium interacts with ascorbic acid &citric acid to have a positive effect on improving hormonal and developmental parameters of maize under stress conditions

3.4 Shoot Dry Weight (g $plant^{-1}$)

Aboveground dry weight, a cumulative indicator of net photosynthetic production, was significantly ($P \leq 0.05$) affected by all individual factors and their interactions (Table 5). Application of 100 kg ha^{-1} potassium significantly increased dry weight compared with the control, which can be attributed to the role of potassium in improving photosynthetic efficiency and facilitating the transfer of photosynthetic assimilates from leaves to growing tissues. Foliar application of ascorbic& citric also significantly increased aboveground dry weight. This can be explained by the fact that ascorbate protects the photosynthetic apparatus (chloroplasts) from oxidative damage, thereby ensuring the continued accumulation of biomass [14]. The interaction between potassium and ascorbate showed a positive effect; however, the most significant effect was observed in the three-way interaction. Treatment ($A_2B_1C_2$) – consisting of 100 kg K ha^{-1}, 400 mg L^{-1} Ascorbic &citric acid and 1 dS m^{-1} salinity – recorded the highest aboveground dry weight of 1.49 g $plant^{-1}$. This result clearly indicates that the protection and salvage mechanisms of this treatment were most effective under extreme stress conditions. While salt stress generally reduces the ability of plants to accumulate biomass, the dual support of potassium (maintaining physiological balance) and Ascorbic &citric acid (providing biochemical protection) enabled the plants not only to survive but also to achieve vigorous growth and dry matter accumulation, surpassing all other treatments. This result is in line with recent studies that have highlighted the effectiveness of combined potassium and ascorbic acid applications in improving growth and yield traits of wheat under

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different conditions. [28, 29, 30, 31].

Table 1. Selected chemical and physical properties of the experimental soil prior to planting for the 2023–2024 season.

Parameter	Value	Unit
pH	7.6	—
Electrical conductivity	2.55	dS m^{-1}
Organic matter	8.59	g kg^{-1}
Ca^{2+}	3.2	mol.kg^{-1}Soil
Mg^{2+}	1.75	mol.kg^{-1}Soil
Na^{+}	2.7	mol.kg^{-1}Soil
SO_4^{2-}	1.3	mol.kg^{-1}Soil
Cl^{-}	0.82	mol.kg^{-1}Soil
$CaCO_3$	0.64	g.kg^{-1}Soil
Available nitrogen	48.2	mg kg^{-1}
Available potassium	159.2	mg kg^{-1}
Available phosphorus	7.69	mg kg^{-1}
Silt	104	g kg^{-1}
Sand	655	g kg^{-1}
Clay	241	g kg^{-1}
Soil texture class	Sand Clay loam	—

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Table 2. Effect of potassium application, Ascobic acid &citric acid foliar spraying, and their interaction on plant height under different irrigation salinity levels.

Potassium added (kg K	Irrigation water salinity (dS m^{-1})		Ascorbic&citric spraying level 0 C0	200 C1		400 C2	A * B
0 (A1)	1	B1	41.5	55.6		49.3	47.1
	3	B2	40.3	50.6		44.2	46.73
100 (A2)	1	B1	53.1	60.1		67.7	60.3
	3	B2	49.9	53.9		59.1	54.3
Mean	Ascorbic&citric		46.2	55.05		55.08	
							Mean A
K	A1 * C		40.9	53.1		46.75	46.92
	A2 * C		51.5	57.0		63.4	57.3
							Mean B
B	B1 * C		47.3	57.85		55.95	53.7
	B2 * C		45.1	52.25		54.2	50.52
L.S.D	A	B	C	A*B	A*C	B*C	A*B*C
0.05	3.00	3.00	7.11	11.51	19.5	22.1	25.4

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Table 3. Effect of potassium application, Ascorbic&citric foliar spraying, and their interaction on leaf number under different irrigation salinity levels.

Potassium added (kg K	**Irrigation water salinity (dS**		**Ascorbic&citric acid spraying** 0 **C0**	200 **C1**	400 **C2**		**A * B**
0 (A1)	1	B1	10.1	11.6	11.1		10.93
	3	B2	9.5	10.7	10.2		10.13
100 (A2)	1	B1	14.3	10.9	12.6		12.46
	3	B2	13.2	10.5	11.1		11.73
Mean	Ascorbic&citric		11.7	10.93	10.25		
							Mean A
K	A1 * C		9.8	11.15	10.65		**10.53**
	A2 * C		13.75	10.7	11.85		**12.1**0
							Mean B
B	B1 * C		11.65	11.25	11.1		11.33
	B2 * C		11.9	10.6	11.4		11.30
L.S.D 0.05	A	B	C	A*B	A*C	B*C	A*B*C
	N.S	0.01	0.61	1.33	2.11	N.S	3.19

NS=non-significant

Table 4. Effect of potassium application, Ascorbic&citric foliar spraying, and their interaction on leaf area under different irrigation salinity levels.

Potassium added (kg K	**Irrigation water salinity (dS**		**Ascorbic&citric spraying level** 0 **C0**	200 **C1**	400 **C2**		**A * B**
0 (A1)	1	B1	155.5	166.6	178.6		162.4
	3	B2	135.5	161.1	170.6		160.23
100 (A2)	1	B1	166.4	186.3	199.1		183.93
	3	B2	145.1	178.9	186.4		170.13
Mean	Ascorbic&citric		150.63	173.23	183.68		
							Mean A
K	A1 * C		145.50	163.85	174.60		161.32
	A2 * C		155.75	182.60	192.75		177.03
							Mean B
B	B1 * C		150.95	176.45	188.85		172.08
	B2 * C		150.30	170.00	178.50		166.27
L.S.D 0.05	A	B	C	A*B	A*C	B*C	A*B*C
	13.16	N.S	20.11	21.33	35.14	26.16	40.6

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Table 5. Effect of potassium application, Ascorbic&citric foliar spraying, and their interaction Shoot Dry Weight under different irrigation salinity levels.

Potassium added (kg K	**Irrigation water salinity (dS**		**Ascorbic&citric spraying level** 0 **C0**	200 **C1**	400 **C2**		**A * B**
0 (A1)	1	B1	1.26	1.36	1.41		1.34
	3	B2	1.19	1.25	1.22		1.22
100 (A2)	1	B1	1.30	1.41	1.49		1.35
	3	B2	1.20	1.31	1.33		1.33
Mean	Ascorbic&citric		1.25	1.34	1.32		
							Mean A
K	A1 * C		1.22	1.30	1.31		1.28
	A2 * C		1.25	1.36	1.36		1.32
							Mean B
B	B1 * C		1.28	1.38	1.37		1.34
	B2 * C		1.19	1.28	1.27		1.25
L.S.D 0.05	A 0.08	B 0.08	C 0.08	A*B 0.13	A*C N.S	B*C **0.17**	A*B*C 0.30

NS=non-significant

Conclusion

This study concluded that potassium fertilizer application combined with foliar spraying of Ascorbic&citric acid a mixture is effective in improving vegetative growth traits of wheat (Abu Ghraib variety). Both treatments (100 kg K ha^{-1} and 400 mg L^{-1} ascorbic acid &citric acid) showed significant improvements in plant height, leaf number, leaf area, and aboveground dry weight when applied alone compared to the control. More importantly, all results showed significant effective synergy and complementarity between foliar spraying of Ascorbic&citric products and potassium fertilizers. The combined treatment (100 kg K ha^{-1} + 400 mg L^{-1} Ascorbic&citric) showed the greatest improvement in all studied traits, indicating that the combined effect was better than the sum of the individual effects. This synergistic effect was particularly evident under salt stress. Under the highest salinity (1 dS m^{-1}) condition, all treatments showed better plant growth (plant height) under the combined application of potassium fertilizer and ascorbic acid &citric acid. This highlights the dual advantage of the combined treatment as a growth promoter and an effective way to further improve plant tolerance to salt stress and mitigate its adverse effects. These results suggest that foliar application of 100 kg of potassium fertilizer per hectare with 400 mg L^{-1} of a mixture of ascorbic acid and citric acid can be considered a sustainable, efficient and environmentally friendly

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agricultural practice, especially for improving vegetative performance on saline soils..

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