EFFECT OF FOLIAR APPLICATION OF POTASSIUM ON THE GROWTH AND YIELD OF TOMATO (*Solanum lycopersicum* L.) UNDER SALINITY STRESS

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ABSTRACT

Salinity stress is one of the most important abiotic stresses, affecting crop's productivity. Potassium plays a major role in the survival of plants under salinity stress conditions in reducing the adverse effects of sodium. A pot experiment was conducted, aiming to study the effect of foliar application of potassium on the growth and yield of tomato (*Lycopersicon esculentum* L.) under salinity stress". The research was performed under two factorial arrangements in a Randomized Complete Block Design (RCBD) and replicated three times at ornamental nursery, department of Horticulture, The University of Agriculture Peshawar during summer, 2022. The levels of potassium for foliar sprays were 0, 0.4, 0.6 and 0.8 ml L^{-1}. Potassium sulphate was used as a source of potassium. The salinity levels of 60 and 90 mM sodium chloride (NaCl) including control were studied. All studied attributes were significantly affected by foliar applied potassium and salinity stress. Interaction between potassium levels and salinity stress were significant for leaves $plant^{-1}$, leaf area, fruits $plant^{-1}$, fruit weight and fruit diameter. Foliar application of potassium significantly increased the growth and yield of tomato. Maximum plant height (63.55 cm), leaves $plant^{-1}$ (19.77), leaf area (0.642 m^2), fruits $plant^{-1}$ (7.77), fruit weight (62.46 g), fruit diameter (54.00 mm), fruit firmness (2.34kg cm^{-2}), ascorbic acid content (14.50 mg $100g^{-1}$of fresh fruit weight) were recorded at the highest level of potassium (0.8 % potassium). Salinity stress reduced the growth and yield of tomato while increased fruit firmness. In case of salinity maximum plant height (63.50 cm), leaves $plant^{-1}$ (20.41), leaf area (0.546 m^2), fruits $plant^{-1}$ (7.66), fruit weight (59.94g), and fruit diameter (54.05mm) while minimum fruit firmness (2.09 kg cm^{-2}) were recorded in control where no salt stress was applied. Data regarding interaction revealed that maximum leaves $plant^{-1}$(24.00), leaf area (0.655 m^2), fruits $plant^{-1}$(9.33), fruit weight (67.58g) and fruit diameter (61.40mm) were observed with the application of 0.8 % of potassium in control conditions where no salinity was imposed. It is concluded that salt sensitive variety of tomato (Rio Grande) could not be grown under salt stress conditions. However, foliar application of Potassium Sulphate (0.8 ml L^{-1}) enhanced growth and yield of tomato under salt stress and it could be adopted as an effective practice to grow tomato variety (Rio Grande) under salinity stress conditions.

Keywords: Foliar application, Growth, Potassium Sulphate, Salinity, Tomato (Rio Grande).

I. INTRODUCTION

Tomato (*Lycopersicon esculentum* L.) belongs to family Solanaceae which is originated from Central America. It is an important summer vegetable crop worldwide. Tomato is a widely grown vegetable over the world due to its flavor, color, high nutritional content and diversified use (Afzal *et al.*, 2013). Tomato is widely used both in cooking and salads, purposes. It is well known for its high nutritional importance as it is a rich source of minerals, vitamins and antioxidants especially lycopene and salicylate (Liu *et al.*, 2004). Tomato is a major horticultural crop. About 130 million tons of tomatoes are produced annually in the world, of which 88 million tones are sold fresh and 42 million tons are processed. Seventy percent of the world's tomatoes are produced in China, India, Turkey, and the United States, which are also the top five tomato producers globally (FAO, 2007). Pakistan produces about 560.6 thousand tons of tomatoes per year. Tomatoes are grown on 8.9 thousand hectares in Punjab, 21.0 hectares in Sindh, 13.3 hectares in Khyber Pakhtunkhwa (KP), and 12.2 hectares in Baluchistan. Tomato production per province is 138.4 thousand tonnes in Punjab, 153.3 thousand tonnes in Sindh, 131.5 thousand tonnes in Khyber Pakhtunkhwa (KP), and 137.4 thousand tonnes in Baluchistan (MINFS&R, 2019). Tomato is a warm-season crop and extremely sensitive to frost. Low humidity, dry winds, and high temperatures frequently harm flower components and inhibit fruit set (Khokhar, 2013). Tomato crop thrive well under an average monthly temperature of 23°C. This crop can withstand drought but fruits are affected by blossom end rot. It cannot be grown successfully in areas with a lot of rainfall. Tomatoes grow well on nearly all types of soil from light sandy to heavy clay. While clay loam and silt-loam soils are best for high yields, light soils are good for an early crop. Loamy soil is best for tomato cultivation. For growing tomatoes, soils with a pH of 5.5 to 7.0 are ideal (Khokhar, 2013). Potassium is a crucial ingredient for increasing the yield of vegetable crops. It significantly improves the quality attributes (Bedari and Hebsur, 2011). Potassium is essential for photosynthesis, enzyme activation, cell and ion homeostasis. Additionally, it contributes to the enrichment of the tomato fruit's lycopene concentration through the synthesis of carotenoids (Bedari and Hebsur, 2011). K is exclusively present inside plants in ionic form. It is co-factor of many enzymes. K has an important part in osmotic adjustment in plants. Potassium is one of the major nutrients, essential for plant growth and development. It is involved in the activation of the enzymes necessary for respiration, nitrogen metabolism, and starch production. Potassium is crucial for photosynthesis, controlling the opening and closing of stomata, transporting nutrients, and absorbing water in plants (Havlin *et al.*, 2005). Additionally, it participates in a variety of physiological processes that regulate plant production, quality, and growth factors (Lester *et al.*, 2010). The ripening of tomato fruit, from green to fully red, involves the accumulation of lycopene and carotenoids, while chlorophyll disappears throughout this process (Barr *et al.*, 2003). Lycopene synthesis is promoted by the application of potassium (Taber *et al.*, 2008). The tomato fruit remains small and lacks a red color when K levels are low. Fruit K content and ripening disorders are closely related (Perkins-Veazie and Robert, 2002). Hybrid tomatoes have a high potassium requirement because of their fast growth and high number of fruits per plant (Chapagain and Wiesman, 2004). Foliar spray is the best way to apply nutrients for intensive and successful tomato crop cultivation (Oded and Uzi, 2003). The crop plants rapidly use the foliar nutrients. It enhances fruit color (Kowalska, 2003). The most major impact on fruit flavour and quality is potassium. K nutrition changes tomato content of vitamin C as well (Perkins-Veazie and Robert, 2002). A low-cost strategy to increase the production of fruit lycopene is potassium nutrition. Lycopene is a crucial substance that promotes health, hence cultivars having higher lycopene contents are being given increased attention. Potassium is an important elements affecting the lycopene content in tomato fruit (Lester *et al.*, 2007). The part of a ripe fruit which is red contains more potassium, acids, and sugars (Adams and Ho, 1995; Taber *et al.*, 2008). Several factors are responsible for the least productivity of tomato in Pakistan. That is the outcome of both biotic (insect, pest, and pathogen, etc.) and abiotic (other environmental factors) elements (temperature, salinity, humidity, environmental changes etc). The losses brought on by the aforementioned issues change seasonally based on environmental factors. One of the most significant environmental issues, salinity greatly reduces the production of any crop, including tomato. Six percent of the world's agricultural land, or more than 800 million hectares, is damaged by salinity. A high incidence of salt also reduces the yield of about 15 million hectares of land (Tilman *et al.*, 2002). One of the main environmental problems preventing the development of agriculture in coastal areas is soil salinity (Yadav *et al.*, 2011). To measure that how plants tolerate salinity, a variety of indices have been established. Analyses of germination rate, germination percentage, changes in leaf area, root length, and biomass accumulation in salty circumstances are some of the methods used to assess a plant's capacity to withstand salinity stress (Munns and Tester, 2008). Salinity is one of the major constraints to development and growth of plants. Salinity stress causes reduction in yield of tomato because the uptake of potassium is affected due to access of sodium ions in the soil solution. Both plant development and productivity of tomato crops cultivated in saline soil are therefore affected by potassium deficiency. A crucial component for increasing vegetable crop productivity is potassium (K), and the amount of K in vegetables has a strong positive correlation with their quality factors. Potassium has a major role in the activation of enzymes, photosynthesis, and cell turgor. Additionally, application of potassium mitigates the effects of salt stress conditions. Its application induces salinity tolerance in plants.

II. MATERIALS AND METHODS

Experimental site

Research on "Effect of foliar application of potassium on the growth and yield of tomato (*Solanum lycopersicum* L.) under salinity stress" was carried out in the Ornamental Nursery Department of Horticulture, The University of Agriculture Peshawar-Pakistan, during the tomato growing season, 2022. The experiment was planned in Randomized Complete Block Design (RCBD) with three replications and two factors. In each replication there were twelve (12) treatments. The experiment consisted of the following two factors; Factor A (Potassium Levels) 0, 0.4, 0.6, 0.8 % and Factor B (Salinity Stress) 0, 60, 90 (NaCl) mM. Seeds of tomato cultivar Rio Grande were sown in module trays in the second week of February 2022. Seedlings were transplanted to polythene bags on 12th March, 2022 when they attained 3-4 true leaf stage. The bags of size 30.48 cm × 35.56 cm having 5 Kg carrying capacity were filled with soil media i.e., GS : Silt : FYM (1:1:1). The seedlings were immediately irrigated after transplantation. Later on subsequent irrigations were practiced on need basis. Weeding was performed regularly throughout the experiment. After collecting data on various growth and yield attributes, analysis of data were done using Statistical package software (Statistix 8.1). Significant data ($P \leq 0.01$) were then subjected to Least Significant Difference (LSD) test for mean comparison.

Salt solution preparation and application.

The salinity levels in this experiment were 0, 60 and 90 mM of sodium chloride (NaCl). Hence, NaCl was weighed by an electric balance for these levels as 0, 3.50g and 5.26g, respectively. Each weighed salt sample was mixed properly with one liter water and irrigation was done with the help of watering cane in each plastic bag. The saline irrigation treatment was started at 10 days after transplantation and irrigation with saline water was repeated several times to maintain the required salinity levels. Electrical conductivity (EC) of the media was measured through EC meter. EC of the media were checked time to time in order to monitor the status of salinity level in the media.

Foliar application of potassium

Potassium Sulphate (SOP) was used as source of potassium which contains 50 % potassium. For 0.4 % potassium, 0.66 g SOP was dissolved in 1000 ml of water. Same procedure was followed for the rest of potassium levels. Three sprays with one week interval were applied to plants. First spray was applied 15 days after transplantation.

Soil Analysis

Before transplanting the seedlings in polythene bags, sowing media were analyzed in the Soil Science Laboratory at The University of Agriculture Peshawar for chemical attributes. Data of the analyzed soil are shown in Table 2.1.

Table 2.1 Properties of sowing medium

Properties	Results
Soil texture	Silt Loam
Organic matter	0.85%
pH	7.8
Phosphorus (P)	7.1 mg kg^{-1}
Nitrogen (N)	0.043 mg kg^{-1}
Potassium (K)	89 mg kg^{-1}
Electric conductivity	0.31 dSm^{-1}

III. RESULTS AND DISCUSSION

Plant height (cm)

Analysis of variance revealed that plant height of tomato was significantly ($P\leq 0.01$) affected by foliar application of potassium and salinity stress, however, interaction of potassium and salinity stress was found non-significant for this trait (Table 3.1a). Mean data (Table 3.1) regarding levels of potassium manifested that maximum plant height (63.55 cm) was attained by plants when 0.8 % of potassium was sprayed. It was closely followed by plant height (61.33 cm) noted at 0.6 % of potassium, while minimum plant height (54.66 cm) was observed for tomato plants in the control treatment. Data concerning salinity stress showed that plant height of tomato was reduced with increasing salinity levels. Those plants which were planted in the control treatments attained the highest plant height (63.50 cm). Whereas, the shortest plant height (55.33 cm) was noted for plants which were subjected to salinity stress of 90 mM. Potassium is one of the most important macronutrients needed for the growth and development of plants. Potassium played major role in the translocation of water and reserve food material within plant body. It increased the rate of photosynthesis, activated the absorption of nitrates and strengthened cell tissue (Yin and Vyn, 2003). Salinity significantly reduced plant height of tomato. This might be due to imbalance nutrient uptake and toxic effects of sodium ion which affected plant growth. Hernandez *et al.* (2014) reported that plants did not show normal growth due to insufficient availability of potassium. Under salt stress conditions, plants showed potassium deficiency due to excess availability of sodium ions (Na^+) in the soil solution. Excess of Na^+ restricted the absorption of potassium ions (K^+) because both the ions had competition for absorption at the exchange sites. Foliar applied potassium was helpful in improving the growth of plant by overcoming deficiency of K^+ in plant tissue. Moreover, potassium was helpful in regulating the opening and closing of stomata, which in turn improved the exchange of water vapor and carbon dioxide. The involvement of potassium in the stimulation of plant growth is also reported by Al-Karaki (2000). Majumdar *et al.* (2000) also reported the positive effect of foliar applied potassium on plant height when sprayed in the range of 0.5%- 0.7 %. Results of the present research are also in agreement with the findings of Zhani *et al.* (2012) in chili and Singh *et al.* (2012) in tomato crop.

Table 3.1 Plant height (cm) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	58.66	54.66	50.66	54.66 D
0.4	62.66	59.00	54.00	58.55 C
0.6	65.66	61.00	57.33	61.33 B
0.8	67.00	64.33	59.33	63.55 A
Mean	63.50 A	59.75 B	55.33 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD (P≤ 0.01) for potassium at 1 % significance level = 1.9819
LSD (P≤ 0.01) for salinity at 1 % significance level = 1.7164

Table 3.1a ANOVA for plant height (cm) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	24.389	12.194		
Potassium levels (K)	3	396.528	132.176	59.41	0.0000
Salinity stress (SS)	2	401.056	200.528	90.14	0.0000
K × SS	6	4.056	0.676	0.30	0.9282
Error	22	48.944	2.225		
Total	35	874.972			

CV 2.51 %

Number of leaves plant^{-1}

Analysis of variance for number of leaves plant^{-1}revealed that potassium, salinity stress and their interaction significantly ($P \leq 0.01$) affected number of leaves plant^{-1}(Table 3.2a). Mean data regarding potassium levels (Table 3.2) manifested that maximum number of leaves plant^{-1} (19.77) was produced when tomato plants were sprayed with 0.8 % of potassium. It was closely followed by leaves plant^{-1} (18.55) obtained at 0.6 % of potassium, while minimum number of leaves plant^{-1} (16.33) was noted for tomato plants in the control treatments. Data concerning salinity stress showed that leaves plant^{-1} were significantly reduced by salinity stress. The least number of leaves (15.58) was produced by those plants which were grown under salinity stress of 90 mM, whereas, the highest number of leaves (20.41) was recorded for plants in the control treatment with no salt stress. Mean data (Fig.3.1) pertaining to interaction revealed that foliar application of potassium significantly increased leaves of tomato under salinity stress. The highest number of leaves (24) was observed with the application of 0.8 % of potassium in control conditions where no salinity was imposed. The least number of leaves plant^{-1}(14.66) was recorded when no potassium was applied of 90 mM salinity level. Foliar application of potassium increased leaves in tomato which might be due to its association with the translocation of water, nutrients and carbohydrates in plant tissue. Khan *et al.* (2009) reported that potassium played vital role in enzyme activation which promoted the production of protein, starch and adenosine triphosphate (ATP). The synthesis of ATP regulated the rate of photosynthesis which resulted in improved vegetative growth. Dkhil *et al.* (2011) also reported increased vegetative growth of potato plants with the foliar application of potassium. Salinity stress adversely affected leaf number plant^{-1} in tomato. Results of the present study showed that number of leaves plant^{-1} was decreased with increasing stress of salinity. Khursheda *et al.* (2015) also documented similar results for tomato crop. They observed that leaves plant^{-1} decreased with the increasing concentrations of NaCl in growing media. Saberi *et al.* (2011) and Jifon and Lester, (2009) also observed the least number of leaves plant^{-1} under salinity stress (10 dS m^{-1}). In the present study, reduction of growth under severe salinity is attributed to decrease in carbon assimilation due to metabolic impairment. The inhibition of plant growth under salinity stress was also attributed to direct inhibition of cell division and expansion Hajiboland *et al.*, 2014; Zhu, 2001; Munns, (2002).

Table 3.2 Number of leaves plant^{-1} of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	17.66	16.66	14.66	16.33 C
0.4	19.00	18.33	15.33	17.55 BC
0.6	21.00	18.66	16.00	18.55 AB
0.8	24.00	19.00	16.33	19.77 A
Mean	20.41 A	18.16 B	15.58 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD ($P \leq 0.01$) for potassium at 1 % significance level = 1.3863
LSD ($P \leq 0.01$) for salinity at 1 % significance level = 1.2005
LSD ($P \leq 0.01$) for interaction = 2.4011

Table 3.2a ANOVA for number of leaves plant^{-1} of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	8.722	4.3611		
Potassium levels (K)	3	57.889	19.2963	17.73	0.0000
Salinity stress (SS)	2	140.389	70.1944	64.49	0.0000
K × SS	6	24.944	4.1574	3.82	0.0093
Error	22	23.944	1.0884		
Total	35	255.889			

CV 5.78 %

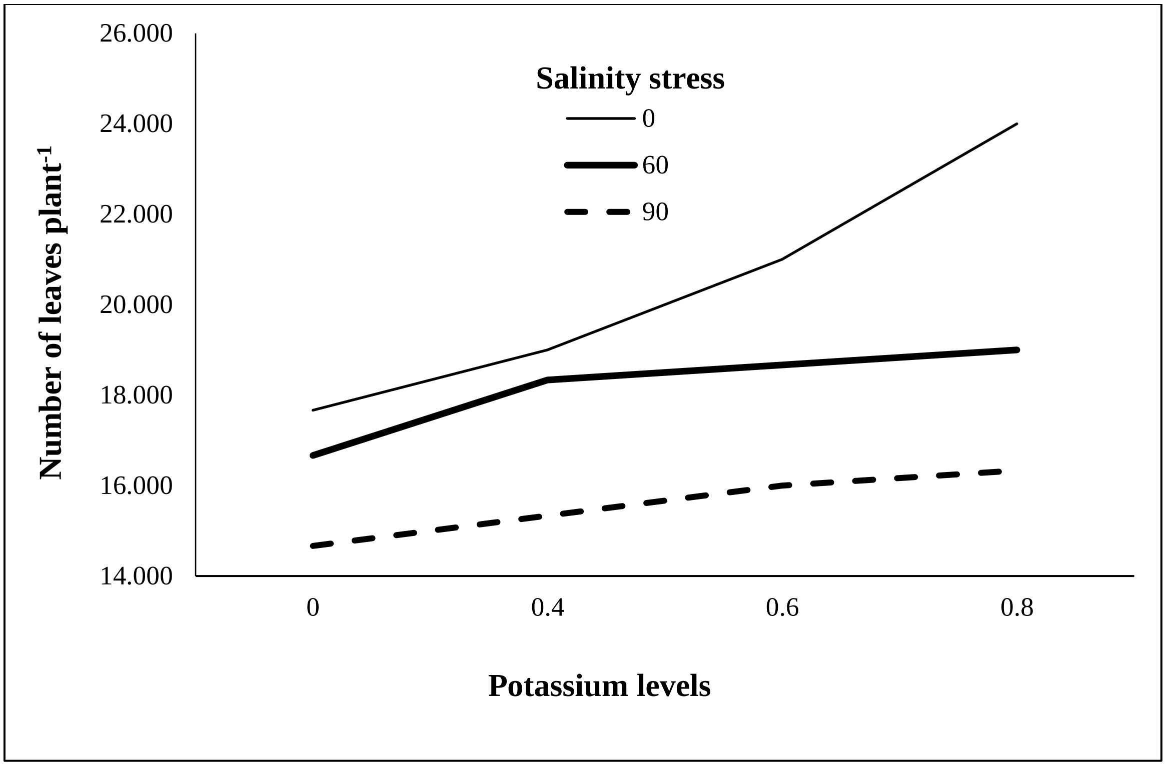

Fig. 3.1. Interaction between potassium levels and salinity stress affecting number of leaves plant^{-1} of tomato.

Leaf area (m^2)

Analysis of variance for leaf area revealed that levels of potassium, salinity stress and their interaction significantly ($P \leq 0.01$) affected leaf area of tomato plant (Table 3.3a).Mean data (Table 3.3) regarding potassium levels manifested that maximum leaf area (0.642 m^2) was attained by plants when 0.8 % of potassium was sprayed. It was closely followed by leaf area (0.552 m^2) observed at 0.6 % of foliar applied potassium, while minimum leaf area (0.376 m^2) was noted for tomato plants in control treatment. Data concerning salinity stress showed that various levels of salinity reduced leaf area of tomato plants. Maximum leaf area (0.546 m^2) was recorded for plants in the control treatment where no salt stress was imposed while minimum leaf area (0.470 m^2) was noted for plants grown under salinity level of 90 mM. Mean data (Fig.3.2) pertaining to interaction revealed that foliar application of potassium significantly improved leaf area under salinity stress. The highest leaf area (0.655 m^2) was observed with the foliar application of 0.8 % of potassium in control conditions where no salinity stress was given. The least leaf area (0.310 m^2), however, was recorded at 90 mM salinity level when no potassium was applied. The outcomes of the present study are supported by Nxele *et al.* (2017). They monitored decrease in leaf area which might be a result of osmotic stress, specific ion effects and ionic imbalance as Na^+ hinders the absorption of K^+. Salt stress negatively affected leaf area and reduced plant growth. However, potassium application as foliar spray enhanced leaf area. It was observed that leaf area under salt stress increased with the optimum supply of potassium fertilizer compared to its deficient levels. Similar results were reported by Amjad *et al.* (2014) in tomato where foliar applied potassium enhanced leaf area under saline conditions.

Table 3.3 Leaf area (m^2) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	0.453	0.365	0.310	0.376 D
0.4	0.506	0.481	0.440	0.476 C
0.6	0.569	0.581	0.505	0.552 B
0.8	0.655	0.648	0.624	0.642 A
Mean	0.546 A	0.519 B	0.470 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD ($P \leq 0.01$) for potassium at 1 % significance level = 0.0307
LSD ($P \leq 0.01$) for salinity at 1 % significance level = 0.0266
LSD ($P \leq 0.01$) for interaction = 0.0532

Table 3.3a ANOVA for leaf area (m^2) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	0.00175	0.00088		
Potassium levels (K)	3	0.34549	0.11516	215.67	0.0000
Salinity stress (SS)	2	0.03541	0.01770	33.15	0.0000
K × SS	6	0.01400	0.00233	4.37	0.0047
Error	22	0.01175	0.00053		
Total	35	0.40840			

CV 4.52 %

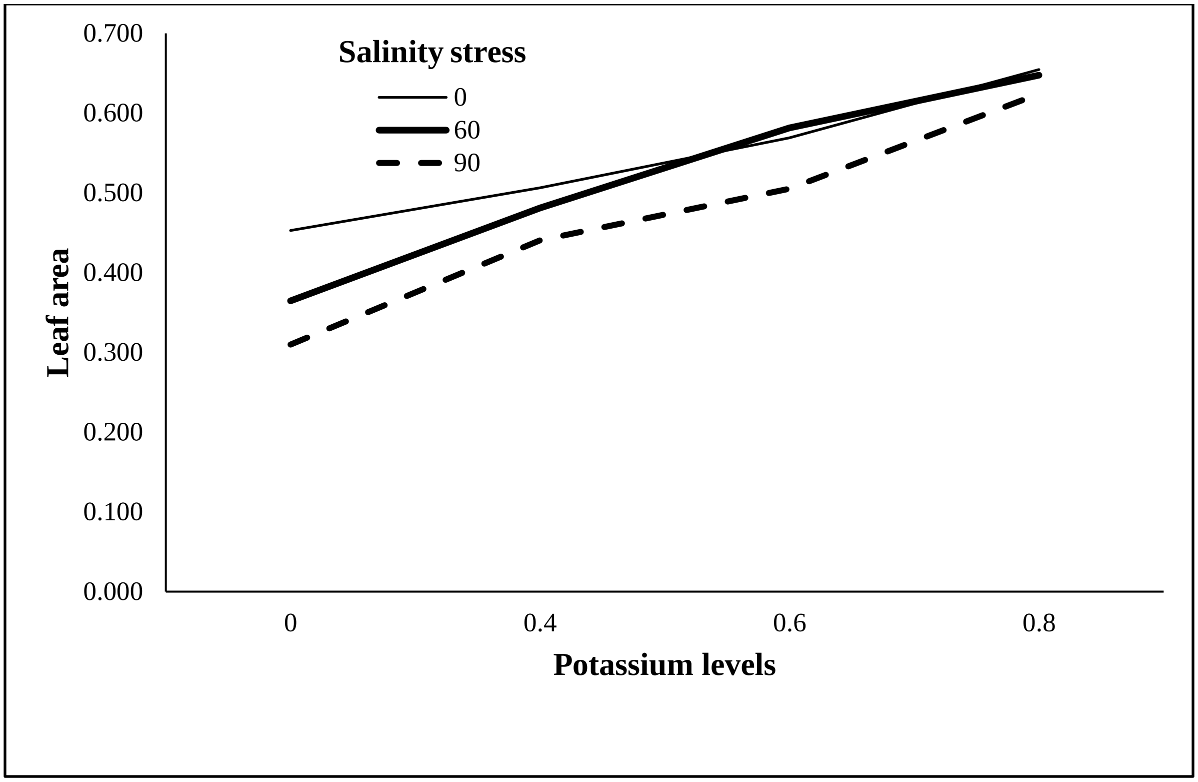

Fig. 3.2. Interaction between potassium levels and salinity stress affecting leaf area of tomato.

Number of fruits plant^{-1}

Analysis of variance for number of fruits plant^{-1} revealed that levels of potassium, salinity stress and their interaction significantly (P≤ 0.01) affected fruits plant^{-1} in tomato (Table 3.4a). Mean data regarding potassium levels (Table 3.4) manifested that maximum fruits plant^{-1}(7.77) were recorded when 0.8 % of potassium was sprayed. It was closely followed by number of fruits (6.77) observed at 0.6 % of foliar applied potassium, while minimum number of fruits plant^{-1} (4.55) was noted for tomato plants in control treatment. Data concerning salinity stress showed that various levels of salinity negatively affected number of fruits plant^{-1}. Those plants which were grown under control environment without salinity stress produced the highest number of fruits plant^{-1} (7.66). Whereas, the least number of fruits plant^{-1} (4.91) were noted for salinity level of 90 mM. Mean data (Fig.3.3) regarding interaction revealed that foliar application of potassium significantly improved fruits plant^{-1} under saline conditions. Maximum number of fruits (9.33) was observed with 0.8 % of potassium application in control treatments where no salinity was imposed. However, minimum number of fruits plant^{-1} (4.00) was recorded at salinity level of 90 mM when no potassium was applied. Potassium application had significant positive effect on the fruit yield of tomato plants in both control and salt-stressed plants. Increase in fruit yield with the application of potassium could be the result of antagonism between potassium and sodium ions Asri, and Sonmez, (2010). In this research, results showed that plants produced less fruits under salinity stress, compared to control. Reduction in fruit yield was caused by limited water availability as well as biochemical and physiological disturbances within plant body due to salt stress (Chen *et al.*, 2007). Application of potassium improved the number of fruit under salinity stress as it lessened the negative effects of salinity.

Table 3.4 Number of fruits plant^{-1} of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	5.33	4.33	4.00	4.55 D
0.4	7.33	6.33	4.33	6.00 C
0.6	8.66	7.00	4.66	6.77 B
0.8	9.33	7.33	6.66	7.77 A
Mean	7.66 A	6.25 B	4.91 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD (P≤ 0.01) for potassium at 1 % significance level = 0.6810
LSD (P≤ 0.01) for salinity at 1 % significance level = 0.5897
LSD (P≤ 0.01) for interaction = 1.1795

Table 3.4a ANOVA for number of fruits plant^{-1} of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	2.889	1.4444		
Potassium levels (K)	3	49.889	16.6296	63.32	0.0000
Salinity stress (SS)	2	45.389	22.6944	86.41	0.0000
K × SS	6	7.278	1.2130	4.62	0.0035
Error	22	5.778	0.2626		
Total	35	111.222			

CV 8.16 %

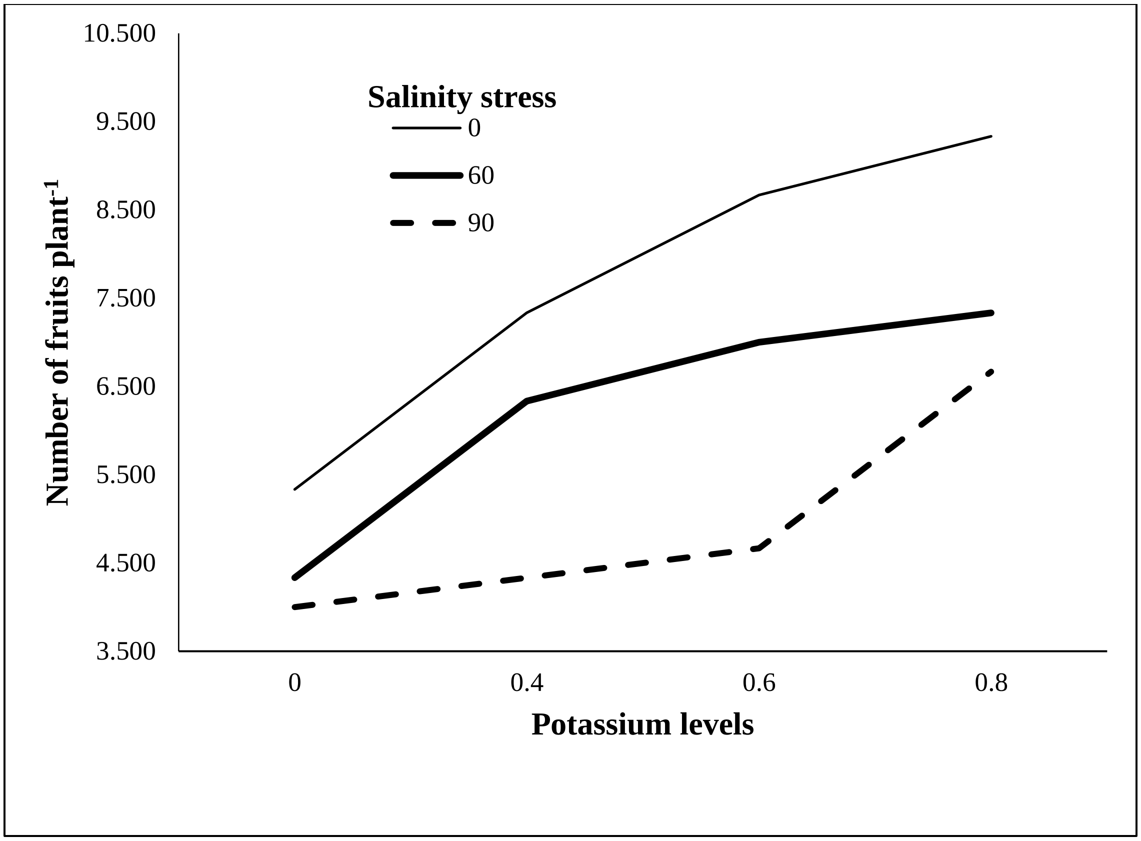

Fig. 3.3. **Interaction between potassium levels and salinity stress affecting number of fruits plant^{-1} of tomato.**

Single fruit weight (g)

Analysis of variance for single fruit weight revealed that levels of potassium, salinity stress and their interaction significantly (P≤0.01) affected fruit weight of tomato (Table 3.5a). Mean data regarding potassium levels (Table 3.5) manifested that the highest fruit weight (62.46gm) was attained by fruits at 0.8 % of potassium. It was followed by fruit weight (58.45g) at 0.6 % of potassium, while the least fruit weight (50.23g) was noted for tomato fruits in the control treatments. Data concerning salinity stress showed that a significant decrease in fruit weight was observed with increasing salinity stress. Those plants which were grown under control conditions where no salt stress was given produced fruits with maximum fruit weight (59.94 g). Whereas, minimum fruit weight (52.49 g) was noted for those plants which were grown under salinity level of 90 mM. Mean data (Fig.3.4) pertaining to interaction revealed that foliar application of potassium significantly improved fruit weight of tomato under salt stress conditions. Higher levels of potassium, significantly reduced the negative effects of salt stress and induced increase in fruit weight. The highest fruit weight (67.58g) was observed when 0.8 % of potassium was applied in control conditions where no salinity was imposed. The least fruit weight of tomato (47.29 g) was recorded when no potassium was applied at 90 mM salinity level. Results of the current study indicated that application of potassium increased fruit weight under salt stress as it reduced the negative effects of salinity. Reduction in fruit weight due to salinity was observed by Cuartero *et al.* (2006). They observed that reduced fruit weight was caused by stunted vegetative growth as salinity reduced water availability and affected biochemical and physiological processes within plant. Findings of the present research were supported by Amjad *et al.* (2014) who obtained similar results in tomato crop. They reported that application of potassium increased fruit weight under salt stress as it minimized the negative effects of salt stress. Ghourab *et al.* (2000) also observed that foliar application of adequate potassium increased fruit weight by increasing translocation of water and photo assimilates to fruit.

Table 3.5 Single fruit weight (g) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	52.63	50.76	47.29	50.23 D
0.4	56.48	54.50	51.58	54.18 C
0.6	63.09	59.08	53.18	58.45 B
0.8	67.58	61.88	57.91	62.46 A
Mean	59.94 A	56.55 B	52.49 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD ($P \leq 0.01$) for potassium at 1 % significance level = 1.5752
LSD ($P \leq 0.01$) for salinity at 1 % significance level = 1.3642
LSD ($P \leq 0.01$) for interaction = 2.7284

Table 3.5a ANOVA for single fruit weight (g) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	11.08	5.539		
Potassium levels (K)	3	755.00	251.666	179.07	0.0000
Salinity stress (SS)	2	334.61	167.304	119.04	0.0000
K × SS	6	37.01	6.169	4.39	0.0046
Error	22	30.92	1.405		
Total	35	1168.61			

CV 2.10 %

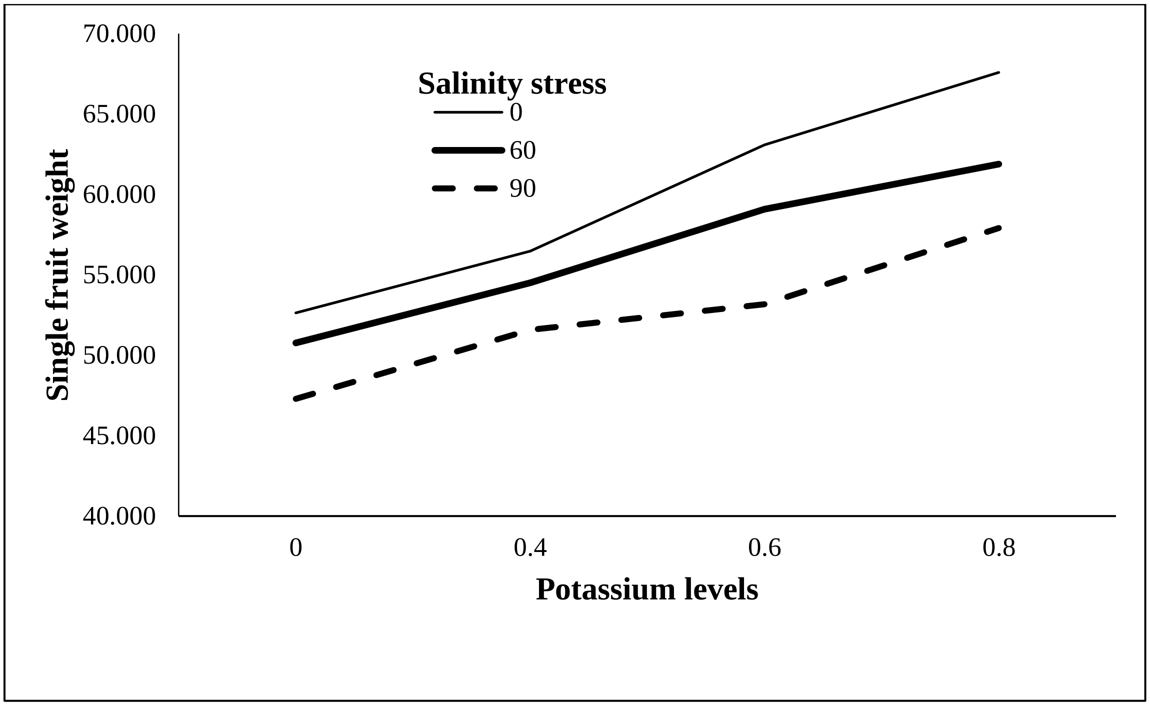

Fig. 3.4. Interaction between potassium levels and salinity stress affecting single fruit weight of tomato.

Fruit diameter (mm)

Analysis of variance for fruit diameter revealed that levels of potassium, salinity stress and their interaction significantly (P≤ 0.01) affected fruit diameter of tomato (Table 3.6a).Mean data regarding potassium levels (Table 3.6) manifested that maximum fruit diameter (54.00 mm) was observed for plants which were sprayed with 0.8 % of potassium. It was followed by fruit diameter (49.82 mm) at 0.6 % of potassium, while minimum fruit diameter (42.80 mm) was noted for tomato fruits in the control treatments. Data pertaining to salinity stress showed that various levels of salinity negatively affected fruit diameter of tomato. A significant reduction in fruit diameter was noted with increasing soil salinity. Those plants which were sown in the control treatments produced fruits with maximum fruit diameter (54.05 mm). Whereas, minimum fruit diameter (42.15 mm) was noted for plants which were grown under salinity level of 90 mM. Mean data (Fig.3.5) regarding interaction revealed that foliar application of potassium enhanced fruit diameter and the highest fruit diameter (61.40 mm) was observed with 0.8 % foliar applied potassium in control conditions where no salinity was imposed. The least fruit diameter of tomato (36.76 mm) was recorded when no potassium was applied at 90 mM salinity level. Results of the present research revealed that salt stress significantly decreased fruit diameter. However, higher potassium levels minimized the negative effects of salinity and caused a significant increase in fruit diameter. Reduction in fruit diameter at elevated salinity could be attributed to suppression of water uptake and water transport to the fruit. Amjad *et al.* (2014) reported similar results in tomato crop. They studied that salinity stress affected fruit size of tomato, however, foliar application of potassium improved fruit diameter under saline conditions. Realizing the relationship between salinity and nutrient is of great economic importance since nutrients may provide protection against salt stress by reducing toxicity of sodium ion through competitive ion uptake and involvement with osmotic adjustment, maintaining ion balance and scavenging of reactive oxygen species under saline conditions (Kumari *et al.*, 2021).

Table 3.6 Fruit diameter (mm) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	**Salinity levels (mM NaCl)**			**Mean**
	0	**60**	**90**	
0	48.40	43.23	36.76	42.80 D
0.4	50.84	47.53	41.08	46.48 C
0.6	55.55	51.56	42.34	49.82 B
0.8	61.40	52.21	48.40	54.00 A
Mean	54.05 A	48.63 B	42.15 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD (P≤ 0.01) for potassium at 1 % significance level = 1.8146
LSD (P≤ 0.01) for salinity at 1 % significance level = 1.5715
LSD (P≤ 0.01) for interaction = 3.1429

Table 3.6a ANOVA for fruit diameter (mm) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	20.69	10.347		
Potassium levels (K)	3	615.97	205.325	110.10	0.0000
Salinity stress (SS)	2	851.97	425.986	228.43	0.0000
K × SS	6	42.91	7.152	3.84	0.0091
Error	22	41.03	1.865		
Total	35	1572.58			

CV 2.83 %

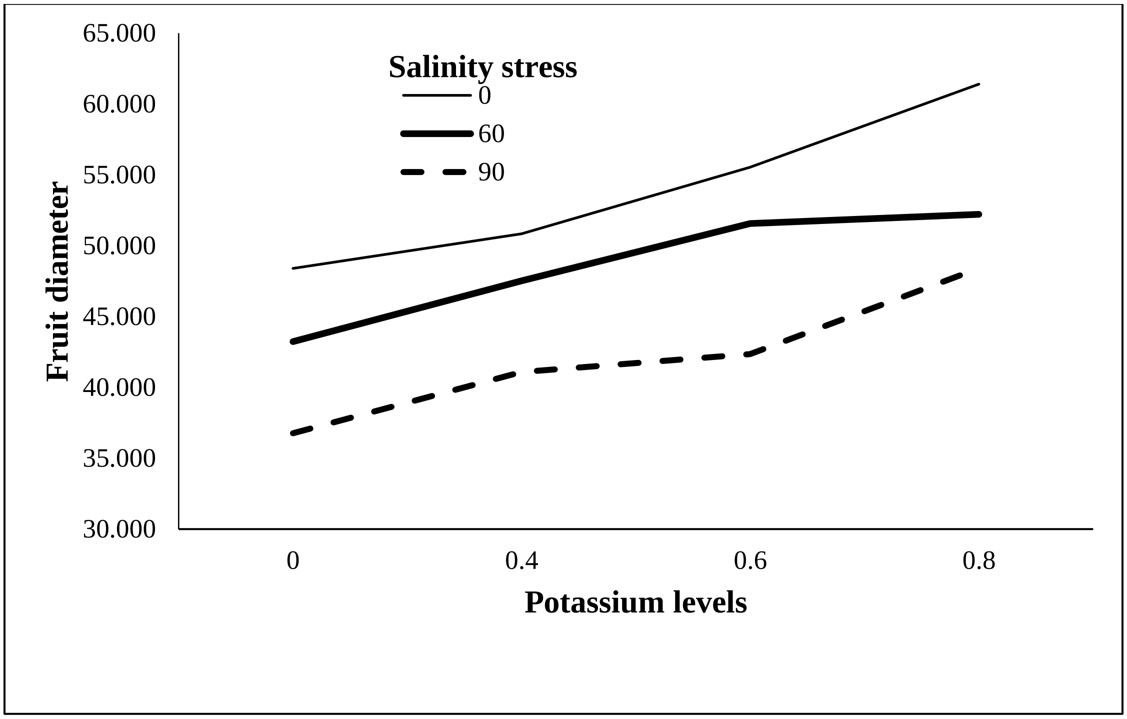

Fig. 3.5. Interaction between potassium levels and salinity stress affecting fruit diameter of tomato.

Fruit firmness (kg cm^{-2})

Analysis of variance for fruit firmness revealed that levels of potassium, salinity stress and their interaction significantly ($P \leq 0.01$) affected fruit firmness of tomato (Table 3.7a).Mean data pertaining to potassium levels (Table 3.7) manifested that maximum fruit firmness (2.34 kg cm^{-2}) was recorded for those fruits which were sprayed with 0.8 % of potassium. It was closely followed by fruit firmness (2.25 kg cm^{-2}) at 0.6 % of potassium, while minimum fruit firmness (2.10 kg cm^{-2}) was noted for tomato fruits in the control treatments. Data concerning salinity stress revealed that various levels of salinity affected fruit firmness of tomato. Fruit firmness increased with increasing levels of salinity. Those plants which were grown in the control treatments produced fruits with minimum fruit firmness (2.09 kg cm^{-2}). While, maximum fruit firmness (2.40 kg cm^{-2}) was observed for fruits at salinity level of 90 mM. Fruit quality was improved by potassium application which could be attributed to overall enhancement of metabolism including mineral uptake, particularly calcium that resulted in higher fruit firmness (Zhao *et al.*, 2001; Lester *et al.*, 2005). Asri and Sonmez (2010) also observed maximum firmness with increasing dose of potassium. With salinity, increase of fruit firmness could be ascribed to reduction of water uptake and transport to the fruit which lowered fruit water content under salt stress conditions and reduced photo assimilates accumulation into the fruits (Javaria *et al.*, 2012).

Table 3.7 Fruit firmness (kg cm^{-2}) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	2.01	2.03	2.28	2.10 D
0.4	2.06	2.13	2.30	2.16 C
0.6	2.10	2.22	2.44	2.25 B
0.8	2.22	2.23	2.59	2.34 A
Mean	2.09 C	2.15 B	2.40 A	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD ($P \leq 0.01$) for potassium at 1 % significance level = 0.0593

LSD ($P \leq 0.01$) for salinity at 1 % significance level = 0.0513

Table 3.7a ANOVA for fruit firmness (kg cm^{-2}) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	0.00244	0.00122		
Potassium levels (K)	3	0.29550	0.09850	49.52	0.0000
Salinity stress (SS)	2	0.64294	0.32147	161.61	0.0000
K × SS	6	0.03735	0.00622	3.13	0.0226
Error	22	0.04376	0.00199		
Total	35	1.02199			

CV 2.01 %

Ascorbic acid content (mg 100g^{-1} of fruit)

Analysis of variance for ascorbic acid content revealed that levels of potassium and salinity stress significantly ($P \leq 0.01$) affected ascorbic acid content, while their interaction was found non-significant. Mean data regarding potassium levels (Table 3.8) manifested that maximum ascorbic acid content (14.50 mg 100g^{-1}) was observed for fruits when 0.8 % of potassium was sprayed. It was closely followed by ascorbic acid content (12.65 mg 100g^{-1} of fruit) at 0.6 % of potassium, while minimum ascorbic acid content (9.49 mg 100g^{-1} of fruit) was noted for tomato fruits in the control treatments. Data concerning salinity stress showed that salt stress significantly increased ascorbic acid content of tomato fruits. Those plants which were exposed to 60 mM of salinity stress produced fruits with maximum ascorbic acid content (13.91 mg 100g^{-1} of fruit). Whereas, minimum ascorbic acid content (9.92 mg 100g^{-1} of fruit) was noted at salinity level of 90 mM. Foliar application of potassium significantly enhanced ascorbic acid content of fruit compared to control treatment. Similar findings were stated by Amjad *et al.*, (2014) in tomato where the foliar application of potassium. Improvement in the quality parameter like enhancement of ascorbic acid content might be possible with the activation of several enzymes which are involved in various metabolic activities of plant. Similarly, Wuzhong (2002) and Bose *et al.*, (2006) also observed a positive relationship between increased potassium application and ascorbic acid contents of tomato fruits. Afzal *et al.*, (2015) also studied the effect of foliar applied potassium on the quality parameters of tomato. They reported that among foliar applied doses of 0.5, 0.6 and 0.7 % of potassium, 0.7 % potassium resulted in maximum ascorbic acid content in tomato. Salt stress increased ascorbic acid content. Similar findings were reported by Denaxa *et al.*, (2022). They also observed reduction in ascorbic acid content in tomato when they are grown under saline conditions. They observed the least amount of ascorbic acid content (0.39 mg g^{-1} fresh weight of fruit) at 4 ds m^{-1} of salt stress in strawberry compared to control (0.5 mg g^{-1} fresh weight of fruit). Reduction of ascorbic acid could be attributed to plant's inability to synthesize it under extreme stress conditions. Ntanos *et al.*, (2021) reported that salinity affected the photosynthetic capability of plant and therefore the photo assimilates required for the biosynthesis of ascorbic acid declined, thus resulted in a decreased amount of fruit ascorbic acid.

Table 3.8 Ascorbic acid content (mg 100g^{-1} of fruit) of tomato as affected by foliar application of potassium and salinity stress

Potassium levels (%)	Salinity levels (mM NaCl)			Mean
	0	60	90	
0	9.55	10.93	7.98	9.49 C
0.4	10.66	13.32	8.89	10.96 BC
0.6	13.04	15.02	9.89	12.65 B
0.8	14.21	16.36	12.93	14.50 A
Mean	11.86 B	13.91 A	9.92 C	

Means followed by different letters are statistically not similar at 1 % significance level.

LSD ($P \leq 0.01$) for potassium at 1 % significance level = 1.7622
LSD ($P \leq 0.01$) for salinity at 1 % significance level = 1.5261

Table 3.8a ANOVA for ascorbic acid content (mg 100g^{-1} of fruit) of tomato as affected by foliar application of potassium and salinity stress

Source	DF	SS	MS	F-Value	P-Value
Replications	2	0.658	0.3292		
Potassium levels (K)	3	126.262	42.0873	23.93	0.0000
Salinity stress (SS)	2	95.384	47.6919	27.12	0.0000
K × SS	6	5.807	0.9678	0.55	0.7645
Error	22	38.692	1.7587		
Total	35	266.803			

CV 11.14 %

IV. Conclusions

Based on the results, the following conclusions are made;

- Foliar application of potassium at the rate of 0.8 % has significantly improved plant height, stem diameter, number of branches plant $^{-1}$, number of leaves plant^{-1}, leaf area, and number of fruits plant^{-1}, fruit weight, fruit firmness and ascorbic acid content of fruit.
- The growth and yield attributes of tomato cv Rio Grande like plant height, stem diameter, number of branches plant $^{-1}$, number of leaves plant^{-1}, leaf area, number of fruits plant^{-1}, fruit weight and ascorbic acid content were notably decreased under medium (60 mM NaCl) and high salinity (90 mM NaCl) stresses.
- The significant interaction revealed that the tested levels of foliar applied potassium reduced the adverse effects of salt stress in tomato crop.

ACKNOWLEDGEMENT

I wish to express gratitude to my honorable advisor Dr. Faiza Aman lecturer, Department of Horticulture, The University of Agriculture Peshawar for her mortal support, consistent advice, encouragement, helpful suggestion, generated the vigor in me to complete this project successful.

CONFLICT OF INTEREST

All the authors declare that they have no conflict of interest.

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