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Salinity Studies in Quinoa (*Quinoa Chenipodoum Willd*) from Haditha Desert, Western of Iraq

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Abstract **- The present studies were conducted to determine the effect of various concentrations of NaCl salinity on germination and growth of four genotypes of *Quinoa Chenopodium Willd*, namely G1 (KVL-SR2), G2 (Q-21), G3 (Q-37), and G4 (Regalona), exposed to 0, 60, 120, and 300 mM NaCl. The study was conducted at the Center of Desert Research, Egypt, and the experiment was carried out in the Plant Physiology Laboratory of the Center of Desert Studies. Seeds were treated with four different levels of NaCl concentration: 0, 60, 120, and 300 mM. The experiment followed a Completely Randomized Design with three replications. The germination experiment aimed to determine the effect of NaCl salinity on seed germination percentage. Seeds were placed in autoclaved petri dishes lined with two layers of filter paper, with fifty seeds per dish. Seeds were treated with 0, 60, 120, and 300 mM NaCl solutions (5 mL). The petri dishes were kept in the laboratory at temperatures ranging from 25°C to 28°C for four weeks. Water loss from the petri dishes due to evaporation was monitored using control petri dishes, and water was added every 24 hours as needed. A pot experiment was conducted using plastic pots containing 1700 grams of fine-sieved soil. Seeds of the aforementioned genotypes were sown in 500 grams of soil, separated from the rest of the pot's soil by a polythene sheet. Plants were watered on alternate days and subjected to salinity treatment 25 days after sowing. Fifty milliliters of nutrient solution (N ratio of 6:4) were also added to the salt solution per pot. The salt solution was applied to the 1200 grams of soil in the pot, and after complete absorption, the polythene sheet separating the soil containing plantlets was removed, allowing the roots of the seedlings to grow into the saline soil in the lower half of the pot. Thinning was done after one week, maintaining five plants per pot. The plants were harvested one month after the salinity treatment. It was observed that the germination percentage decreased as the salinity level increased. G1 was tolerant, while G4 was salt-sensitive compared to the other genotypes. Plant height, number of leaves, and number of nodes per plant decreased with increasing salt concentration. G3 was least affected, followed by G2, G1, and G4. Fresh weight, dry weight, and percentage water content of the plants also significantly decreased with increased salinity. The distribution of Na+ ions in various plant parts showed a high concentration in the roots, stem, leaf blade, and leaf sheath of all genotypes. The highest concentration of Na+ ions was found in the leaf sheath of all genotypes, followed by the stem, root, and leaf blade, with high water content even under the highest salt levels. An effective partition of Na+ and Cl- ions in the leaf sheath and the transport of K+ to the physiologically important leaf blade were observed in G1, while other genotypes did not exhibit this efficiency. The specific ion effect of NaCl on the total N status of plants was most pronounced in G1, followed by G2 and G3, while G4 maintained optimal N levels in the root and leaf blade. The tolerant genotype G1 could be utilized for rehabilitation in salt-affected areas.**
Keywords: **NaCl Salinity, Quinoa Genotypes, Germination Percentage, Ion Distribution, Salinity Tolerance**

I. INTRODUCTION

Human dependence on soils is significant, and good soils are, to some extent, dependent on human management. Soils are natural mediums in which plants grow. Humans benefit from these plants either for their beauty or their ability to supply food and fiber for themselves and their animals. The quality of soil often determines living standards, particularly through the types and quality of plants grown. Great civilizations have almost invariably relied on good soils as one of their primary natural resources. Moreover, these civilizations have remained prosperous only as long as they properly cared for their soils.

The Iraqi economy relies heavily on oil and agriculture, with soil being a fundamental resource. Studies on crop yield in Iraq suggest that soil salinity is a significant factor contributing to decreased yields. The magnitude of damage caused by soil salinity is alarming, necessitating a multidimensional approach to address it. The presence of salts above a certain threshold renders soil saline. Increasing salinization is a major constraint on crop production, primarily due to four salts: sodium sulfate, calcium chloride, magnesium chloride, and sodium chloride [34]. While some plants require sodium as a micronutrient [10], this is not true for all plants. Sodium chloride can enhance growth at low concentrations, but higher concentrations decrease germination percentage and other growth parameters.

The mechanism of salt tolerance in quinoa is not well understood. This study was undertaken to

1. Determine the response of various quinoa genotypes to sodium chloride salinity.
2. Investigate the mechanism of absorption and distribution of Na+ and Cl- ions in different plant parts.
3. Gain a comprehensive understanding of salinity tolerance in quinoa and its biotypes.

Soil salinity affects extensive areas in the Middle East and North Africa. Large regions in Iraq, India, Pakistan, and

Egypt have become agriculturally unproductive. The region's climate, characterized by alternating winter rainfall and summer drought, results in moisture accumulation during winter, followed by progressive moisture depletion in summer. In many areas, inadequate rainfall or other water resources prevent the removal of accumulated salt from the soil through leaching. Consequently, rain-fed areas often suffer from salt buildup in the topsoil. The level of salinization influences cropping patterns. Soil with an electrical conductivity (EC) higher than 4 dS/m is usually considered marginal [15]. However, quinoa is sometimes cultivated in areas with salinity concentrations exceeding 10 dS/m. While plant death may occur under extreme conditions, reduced vegetative growth and decreased grain yield are more common consequences of salinity [38]. In arid regions, the combined effects of salinity, drought, and high temperatures further decrease crop productivity. Efforts to improve salt tolerance in cultivated varieties have been hindered by a lack of understanding of the mechanisms of salt tolerance and how they are influenced by environmental factors [20]. Quinoa is a major source of human feed in many countries and is widely grown on salt-affected or newly reclaimed lands. The information obtained from this study aims to enhance quinoa's tolerance to saline conditions and improve its productivity.

The main objectives of this study were:

1. To determine the effect of different levels of NaCl salinity on germination and growth of four quinoa genotypes.
2. To identify salinity-related parameters that most predict decreases in quinoa yield.
3. To investigate the relative importance of toxicity stress components of salinity on quinoa growth.

II. MATERIALS AND METHOD

The present work was undertaken to determine the effect of different NaCl salinity levels on germination and growth for genotypes of *Quinoa chenopodium Willd.*, specifically G1 (KVL-SR2), G2 (Q-21), G3 (Q-37), and G4 (Regalona). Seeds were obtained from the Center of Desert Research, Egypt. The seeds were treated with four different NaCl concentrations: 0, 60, 120, and 300 mM. The experiment was conducted using a Completely Randomized Design with a factorial arrangement, including four treatments and three replications.

A seed germination experiment was performed to assess the effect of NaCl salinity on seed germination percentage. Seeds were placed in autoclaved Petri dishes lined with a double layer of filter paper, with fifty seeds per dish. Seeds were treated with 0, 60, 120, and 300 mM NaCl solutions (5 mL). The Petri dishes were kept in the laboratory at a temperature of 25–28°C for four weeks. Water loss from the Petri dishes due to evaporation was monitored using a control Petri dish, and water was added every 24 hours.

A pot experiment was conducted in plastic pots containing 1700 grams of fine sieved soil. Seeds of the aforementioned genotypes were sown in 500 grams of soil, which was separated from the remaining soil in the pot by a polyethylene sheet. Plants were watered on alternate days and subjected to salinity treatment 25 days after sowing. A 50 mL nutrient solution comprising N and P (6:4) was also added to the salt solutions per pot. Salt solution was applied to the 1200 grams of soil in the pot. After complete absorption, the polyethylene sheet separating the soil containing plantlets was removed to allow the seedlings' roots to grow into the saline soil in the lower half of the pot [4].

Thinning was done after one week, and the number of plants per pot was maintained at five. The plants were harvested one month after the salinity treatment. Parameters noted included plant height (cm), number of leaves, number of nodes, fresh weight (g), dry weight (g), and water content (%) calculated using the formula provided by [30]. The plant material was used for chemical analyses. It was separated into root, stem, leaf blade, and leaf sheath and cut into fine pieces. Na^+ and K^+ were determined using the dry ash method. A sample of the separated plant material (root, stem, leaf blade, leaf sheath) was added with CaO (at 1/4th of the plant material weight) to prevent ion loss during dry ashing [8]. A small amount of distilled water was added to wet the plant material, which was then placed in a Muffle Furnace (Model L.47-T) at 500°C for three hours. The dry ash was dissolved in 0.5 N HNO_3 [12], filtered, and analyzed for Na^+ and K^+ using a flame photometer (Corning 400). Chloride ions were also detected using dry ashing, with estimation performed by a Corning Chloride Analyzer (Model 90). Nitrogen content in roots, stems, and leaves was determined using the Kjeldahl method [33].

Statistical analysis of the data was performed using a Completely Randomized Design with a factorial arrangement. Treatment means were compared using Duncan's Multiple Range Test [29]. Parameters noted included average plant height (cm), number of leaves, number of nodes (five plants were counted and their mean calculated), fresh and dry weight (g) (Bosch AE 160), and water content (%) calculated using the formula provided by [30]. Plant materials were used for chemical analysis, with Na^+ and K^+ analyzed as per [11], Cl^- ion estimation conducted using the Corning Chloride Analyzer Model 90 (Essex, U.K.), and nitrogen content determined using the Kjeldahl method [33]. Statistical analysis was performed using a Completely Randomized Design with factorial arrangement, and treatment means were compared using Duncan's Multiple Range Test with Mstat-C software [29].

III. RESULTS OF THE STUDY

The reduction in dry matter yield due to salt stress was assessed for each genotype based on a 50% reduction in dry matter yield. G1 was found to be the most tolerant of all the genotypes, with a tolerance limit of 120 mM NaCl, followed by G2, G3, and G4 with NaCl tolerance limits of 150 mM and 300 mM, respectively.

TABLE I EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON GERMINATION (%)

Genotypes	Level	Germination (%)
G1	0	58.0 ± 10.59
	60	58.66 ± 0.15
	120	47.33 ± 06.11
	300	14.00 ± 02.00
G2	0	60.66 ± 07.57
	60	58.00 ± 03.46
	120	44.00 ± 04.06
	300	15.33 ± 06.4
G3	0	58.66 ± 02.30
	60	40.00 ± 05.29
	120	17.33 ± 03.05
	300	06.66 ± 02.33
G4	0	63.33 ± 03.05
	60	47.33 ± 02.30
	120	42.66 ± 05.77
	300	10.00 ± 06.00
L.S.D (p< 0.05)	Treatment	08. 14
	Genotype	08.14
	(Tr. Acc.)	N.S

Mean ± Standard Deviation

When seeds were exposed to high levels of salinity, a remarkable decrease in germination was observed (Table I). It was noted that there was an increase in percentage germination when seeds were exposed to 60 mM NaCl in all genotypes. However, a significant decrease in percentage germination occurred at higher NaCl concentrations, especially at 300 mM. Among the genotypes, G1 was the most salt-tolerant, followed by G2, G4, and G3. Seed germination is considered the most sensitive stage and is adversely affected by increasing salt concentration [31]. However, in certain plants, a low degree of stress may promote germination. S. Allen *et al.,* [25] studied tolerance during germination in alfalfa and proposed that the inhibitory effect of NaCl on water uptake by seeds was significant. In the present experiment, an increase in percentage germination was observed at lower levels of salinity, followed by a decrease at higher salt levels. G1 was observed to be the most tolerant genotype, while G3 was found to be the most salt-sensitive at the germination stage. According to [22], the inhibitory effect of NaCl is primarily osmotic in barley, but calcium is known to alleviate this inhibition.

The data collected for various plant growth parameters are presented in Table II. It is evident from the values in Table II that NaCl had an inhibitory effect on plant height, leaf production, and number of nodes in all genotypes under study, with G2, G3, and G4 being the most affected.

TABLE II EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON PLANT HEIGHT, NUMBER OF NODES, AND NUMBER OF LEAVES OF *Quinoa Chenopodium Willd*

Genotypes	Level	Plant Height	No. of Nods	No. of Leaves
	0	55.0 ± 5.00	8.33 ± 0.57	19.66 ± 58
	60	63.5 ± 1.00	8.66 ± 1.75	24.66 ± 4.24
	120	45.66 ± 6.92	7.33 ± 1.52	13.66 ± 4.04
G2	300	43.23 ± 6.04	6.86 ± 1.52	12.33 ± 0.51
	0	55.66 ± 7.09	7.33 ± 1.52	17.66 ± 2.51
	60	67.73 ± 8.43	6.66 ± 2.30	17.66 ± 4.72
	120	44.33 ± 9.45	6.66 ± 0.59	15.33 ± 4.50
G3	300	40. 60 ± 0.13	5.00 ± 2.00	12.00 ± 3.46
	0	52.00 ± 4.35	8.00 ± 1.00	19.33 ± 3.08
	60	48.3 ± 7.92	6.66 ± 2.51	13.66 ± 3.50
	120	45.00 ± 19.67	6.00 ± 2.00	1.66 ± 2.71
G4	300	40.83 ± 12.85	5.00 ± 0.00	10.00 ± 1.00
	0	47.16 ± 11.12	7.66 ± 1.52	17.66 ± 3.63
	60	38.73 ± 6.58	6.66 ± 1.21	17.00 ± 3.54
	120	12.16 ± 8.51	5.33 ± 1.05	14.00 ± 4.48
G1	300	28.00 ± 8.59	4.33 ± 1.00	10.00 ± 3.00
	0	55.0 ± 5.00	8.33 ± 0.57	19.66 ± 58
	60	63.5 ± 1.00	8.66 ± 1.75	24.66 ± 4.24
	120	45.66 ± 6.92	7.33 ± 1.52	13.66 ± 4.04
L.SD (pc <0.05) Treatment		8.415	N.S	N.S
Genotype		8.415	N.S	N.S
(Tr×Acc)		N.S	N.S	N.S

G4 exhibited a significant ($p < 0.05$) difference from the other genotypes in terms of plant growth, leaf production, and number of nodes, with its growth being notably hampered by NaCl. The higher growth response observed in G2 indicated its higher tolerance to NaCl salinity. Similarly, G1 also showed a high growth response, reflecting its tolerance to NaCl salinity.

Fresh and dry matter yields of plants are considered indicators of tolerance or non-tolerance to salinity. Plants exhibiting higher yields are considered more tolerant. Plants with higher water content at elevated salt levels are better able to tolerate salinity. The results of the present experiment with four genotypes of *Quinoa Chenopodium Willd* for changes in fresh and dry matter yield and percent water content at 60, 120, and 300 mM NaCl levels are presented in Table III. The data indicate a significant ($p < 0.05$) gradual decrease in fresh and dry matter yield of both shoot and root for all genotypes under study with increasing salt concentration. Significant ($p < 0.05$) genotype differences in fresh and dry matter yield, even at 300 mM NaCl concentration, were observed, with G4 being the most affected, showing high sensitivity to salinity. G2 was ranked second, followed by G3. The water content percentage of the shoots of all genotypes was significantly ($p < 0.05$) reduced under elevated NaCl levels, whereas the reduction in root water content was not significant. The effect on water absorption by the roots was less conspicuous compared to the shoots. The shoot of G1 retained significantly ($p < 0.05$) higher water content, which was severely reduced with a progressive increase in salinity.

TABLE III EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON FRESH WEIGHT, DRY WEIGHT, AND WATER CONTENT (%) OF LEAVES IN *QUINOA CHENOPODIUM WILLD*.

Genotypes	Level	Fresh Weights (gm)	Dry Weights	Water Content
G1	0	3.29 ± 0.22	13.77 ± 0.50	0.42 ± 0.07
	60	3.13±1.24	14.14±1.64	0.42±0.07
	120	2.82±0.81	10.58±3.21	0.38±0.06
	300	1.84±0.53	08.10±2.36	0.25±2.36
G2	0	4.18±0.83	12.70±2.20	0.52±0.13
	60	2.42±0.69	11.20±0.62	0.30±0.17
	120	2.12±0.95	11.22±1.94	0.27±0.12
	300	1.40±0.61	06.41±2.42	0.18±0.06
G3	0	3.21±0.82	14.7±2.02	0.36±0.12
	60	2.35±1.04	1.04±1.96	0.28±0.18
	120	1.05±0.44	10.27±2.57	0.13±0.04
	300	0.37±0.19	05.15±0.90	0.05±0.01
G4	0	1.79±0.95	10.94±4.42	0.18±0.08
	60	1.63±0.42	08.16±1.48	0.19±0.07
	120	0.67±0.72	04.21±2.47	0.08±0.05
	300	0.19±0.19	01.98±0.27	0.03±0.0
L.SD (pc <0.05)	Treatment	0.826	2.333	0.083
	Genotype	0.826	2.333	0.083
	(Tr×Acc)	N.S	N.S	N.S

Mean ±standard deviation

In the present investigation, all genotypes subjected to increasing levels of NaCl were analyzed for the distribution of Na^+, K^+, Cl^-, and total ionic partitioning. The data regarding the distribution of Na^+ in the root, stem, leaf sheath, and leaf blade are shown in Table 4. It is evident from the experimental results that the Na^+ levels in the root, stem, leaf sheath, and leaf blade increased in all genotypes with a concomitant increase in NaCl salinity. A statistically significant ($p < 0.05$) difference in Na^+ distribution was observed among NaCl levels, genotypes, and plant parts; however, the quantity of Na^+ ions varied greatly among different parts.

In this investigation, all genotypes subjected to increasing NaCl levels were analyzed for the distribution of Na^+, K^+, Cl^-, and total ionic partitioning. The data regarding Na^+ distribution in the root, stem, leaf sheath, and leaf blade are shown in Table IV. It is evident from the experimental results that the Na^+ level in the root, stem, leaf sheath, and leaf blade increased in all genotypes with a concomitant increase in NaCl salinity. Statistically significant ($p < 0.05$) differences in Na^+ distribution was observed among NaCl levels, genotypes, and their parts. However, the quantity of Na^+ ions varied greatly in different parts of the same plant.

TABLE IV EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON THE DISTRIBUTION OF NA^+ (MM/G DRY WEIGHT).

Genotypes	Level	Plant Roots	Stem	Leaf Sheath	Leaf Blade
G1	0	108.26±08.40	288.90±18.55	908.60±55.71	738.43±30.07
	60	190.03±12.41	396.96±17.69	1361.80±49.20	790.10±48.04
	120	245.10±11.85	442.10±13.45	1420.96±68.52	809.40±68.08
	300	284.96±18.14	453.3±34.00	1627.36±103.74	989.3±72.85
G2	0	123.83±06.71	286.40±19.87	913.80±42.95	696.20±40.93
	60	202.83±06.71	414.93±26.47	1133.46±87.52	800.70±31.01
	120	243.26±19.68	458.36±21.97	1268.16±34.67	950.06±.90
	300	312.23±14.23	477.20±17.99	1647.26±92.22	1088.63±18.42
G3	0	142.40±13.17	419.06±.12.62	926.26±27.5	688.56±31.02
	60	253.90±08.27	458.66±15.09	1141.00±33.111	935.43±16.93
	120	282.06±14.04	504.13±14.67	1267.70±32.00	968.06±37.89
	300	338.40±10.40	534.93±22.47	1690.00±45.43	11168.13±33.39
G4	0	163.96±04.36	471.70±26.42	888.80±41.10	614.93±32.71
	60	239.50±15.84	457.80±3.15	1133.00±28.21	837.73±50.21
	120	345.20±22.30	693.50±18.75	1251.00±28.21	863.93±59.38
	300	362.50±30.74	725.40±32.95	1543.76±91.94	1222.56±67.64
L.SD (pc <0.05)	Treatment	12.82	21.53	55.37	37.31
	Genotype	12.82	21.53	N.S	37.31
	(Tr×Acc)	25.64	43.06	110.7	74.6

Mean ±standard deviation

Genotype G1 was able to maintain a considerably lower Na^+ level in the leaf blade, followed by the stem and root. It appeared to exclude a large portion of Na^+ to the leaf sheath, thus avoiding its transport to the leaf blade. Moreover, under non-stressed (control) conditions, G1 seemed to selectively retain Na^+ for growth and metabolism.

TABLE V EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON DISTRIBUTION OF K^+ (MM/G DRY WEIGHT).

Genotypes	Level	Plant Roots	Plant Stem	Leaf Sheath	Leaf Blade
G1	0	271.46±11.37	459.93±10.69	760.40±43.25	768.36±28.55
	60	280.16±04.77	475.96±51.85	650.60±16.72	765.50±45.85
	120	197.70±11.03	395.76±19.95	607.36±29.21	680.60±29.18
	300	150.46±14.97	344.00±24.21	465.86±23.15	580.83±17.35
G2	0	315.56±22.31	458.33±27.80	771.96±49.38	768.46±36.44
	60	297.30±16.73	476.60±09.26	777.30±31.64	750.83±36.55
	120	205.96±07.03	415.96±22.03	646.80±27.46	639.43±34.07
	300	166.33±12.13	360.70±2.70	471.26±12.78	344.30±3.06
G3	0	314.70±11.05	488.110±27.74	778.23±35.68	788.90±34.70
	60	298.86±15.79	492.90±20.35	711.66±28.53	695.41±37.36
	120	208.20±24.27	445.20±30.83	710.30±19.83	641.90±45.80
	300	162.50±08.40	369.46±28.90	496.36±16.45	531.26±33.92
G4	0	346.83±20.01	759.33±40.9	1055.80±11.19	866.73±03.47
	60	297.43±07.25	702.13±20.29	867.80±28.92	632.50±19.83
	120	201.46±16.05	598.76±22.119	821.66±12.63	616.60±25.28
	300	149.13±16.87	447.30±36.77	516.60±19.76	519.40±25.87
L.SD (pc <0.05)	Treatment	15.77	23.32	23.31	26.83
	Genotype	15.77	23.32	23.31	N.S
	(Tr×Acc)	N.S	46.64	46.63	53.65

Mean ±standard deviation

The Na^+ level in the root of this genotype was significantly ($p < 0.05$) lower than in all other genotypes tested. G2 exhibited comparatively higher Na^+ levels in the root, followed by G3 and G4, compared to G1. Similar to G2, the remaining three genotypes transported the majority of Na^+ to the leaf sheath, but G1 was distinct in its Na^+ transport to the leaf sheath compared to their respective control genotypes. G1 also remained distinct with respect to Na^+ distribution in the leaf blade, where it was markedly lower than in G2, followed by G3 and G4. The roots of G2, G3, and G4 showed significantly ($p < 0.05$) higher Na^+ content than G1. The results pertaining to Cl^- distribution in the root, stem, leaf sheath, and leaf blade under increasing salinity levels among the genotypes are presented in Table V.

A highly significant ($p < 0.05$) genotype difference in Cl^- distribution with varying salinity levels was observed. The distribution of Cl^- closely paralleled that of Na^+. Genotype G1 demonstrated effective control over Cl^- distribution, with a notably lower Cl^- level in the leaf blade compared to the other genotypes. All plant genotypes transported the majority of Cl^- ions to the leaf sheath. G1 retained a lower Cl^- level in the root and stem, whereas the other three genotypes did not exhibit this characteristic effectively, resulting in statistically significant ($p < 0.05$) differences. No genotype showed ion selectivity for Cl^-, in contrast to Na^+. Genotype G1 maintained effective control over both Na^+ and Cl^- distribution, while this capability was significantly lower in the other three genotypes.

The data on the changes in K^+ distribution in the root, stem, leaf sheath, and leaf blade of four genotypes of *Quinoa Chenopodium Willd.* under increased salt levels are presented in Table 6. The results indicate that the K^+ status in all plant parts differed significantly ($p < 0.05$) under elevated NaCl salinity. The K^+ level in the root of G1 was lower than that in the other three genotypes, and a similar trend was observed for K^+ distribution in the stem. However, in the leaf sheath of G1, the K^+ content was significantly ($p < 0.05$) lower than in G2, G3, and G4, with a linear progression in salinity level. Genotype G1 transported the majority of the observed K^+ to the leaf blade even under the highest salt levels, showing highly significant ($p < 0.01$) differences compared to the other genotypes, which transported a significant portion of K^+ to the leaf sheath or stem.

TABLES VI EFFECT OF DIFFERENT LEVELS OF NACL SALINITY ON DISTRIBUTION OF CL^+(MM/G.DW)

Genotypes	Level	Plant Roots	Plant Stem	Leaf Sheath	Leaf Blade
G1	0	76.30±07.6	215.66±09.01	477.76±27.77	376.96±49.07
	60	240.20±10.27	403.50±13.39	1221.00±83.35	607.70±18.55
	120	280.00±09.27	406.43±07.25	1283.70±09.86	722.76±35.49
	300	291.13±10.69	534.16±33.98	1672.33±66.22	876.06±74.17
G2	0	79.73±10.10	217.56±15.42	433.10±15.78	331.76±21.60
	60	286.83±16.70	405.66±16.01	1234.66±59.91	739.00±63.33
	120	342.96±16.19	452.20±29.11	1359.10±41.59	737.00±63.66
	300	370.20±3.75	533.33±30.55	1667.33±61.69	948.66±43.61
G3	0	99.40±09.86	227.16±23.90	429.56±21.94	333.83±20.43
	60	325.116±26.13	440.06±46.80	1087.36±26.44	720.70±42.25
	120	337.00±04.32	468.00±07.54	1233.33±58.59	841.33±31.56
	300	398.76±22.79	600.53±50.80	1649.66±26.94	1007.76±18.45
G4	0	92.48±06.93	248.06±22.66	554.13±16.56	476.06±40.52
	60	338.33±20.81	477.66±28.57	1081.63±86.63	705.66±12.01
	120	395.70±18.92	656.66±51.31	1265.30±83.58	845.53±52.18
	300	424.43±44.67	743.33±35.11	1673.33±64.29	1187.33±71.14
L.SD (p<0.05	Treatment	15.65	24.82	46.78	36.18
	Genotype	15.64	24.82	N.S	36.18
	(Tr×Acc)	31.30	49.65	93.55	72.36

Mean ±standard deviation

The retention of higher K^+ levels in the leaf blade indicates greater salinity tolerance of G1 compared to the other genotypes. Genotype G4 showed the least effective distribution of K^+ in all parts studied under increased salinity stress.

The distribution of nitrogen in the root, stem, and leaf of all genotypes has been analyzed and is presented in Table 7. The data reveal that the percentage of nitrogen consistently decreased in the roots with increasing salinity levels in G2 and G4. In G1, the percentage of nitrogen decreased non-

significantly with increasing salinity levels compared to non-stressed plants. All genotypes showed a non-significant general increase in stem nitrogen levels, indicating retention in the stem to a small extent under both saline and non-saline conditions. Leaf nitrogen remained constant in G1 but increased non-significantly in G2, G3, and G4 under salinity stress.

IV. DISCUSSION OF THE STUDY

A. Plant Growth, Fresh and Dry Matter Yield

Sodium chloride applied in reduced amounts is known to enhance growth and dry matter production. However, when its concentration in the nutrient solution or soil exceeds a certain threshold level, a reduction in growth and growth characteristics begins [9]. NaCl applied in amounts higher than optimal reduces top growth [18] and can either increase [1] or decrease [4] root growth. T. McKimmie *et al.,* [19] observed a reduction in nodes and leaves of alfalfa plants under saline conditions. In the present experiment, reductions in plant height, number of leaves, and number of nodes were observed, with significant differences among the genotypes concerning these parameters. The higher plant growth exhibited by G1 indicates the tolerance of this genotype to increasing levels of NaCl salinity [18, 7, 28].

Plants exposed to increasing levels of salinity experience a significant reduction in fresh and dry matter yield and water content [18, 7]. There is considerable variation in salinity tolerance and dry matter production among different plant genotypes [6, 18, 14].

In this study, a large variation in fresh and dry matter production and water content was observed among the four genotypes of quinoa under increasing salinity. G1 was better able to absorb more water even at the highest salt levels, exhibiting high dry matter production and showing greater salinity tolerance compared to the other genotypes under study [32, 5, 14, 16].

B. Nitrogen Content

Changes in nitrogen absorption and its transport in plants under NaCl have been reported. M. Passarakili *et al.,* [17] observed an increased nitrogen content in maize plants under salinity. [10] demonstrated stimulation in the uptake of NO3- under low levels of Na+. The results of the present investigation for nitrogen status in plants showed that the tolerant genotype exhibited an accumulation of nitrogen in the leaves. The accumulation of nitrogen in the leaves of sensitive genotypes appeared to be due to the specific ion effect of Na+ [26]. The Na+ and Cl- ions interfere with physiological processes in the cytoplasm, including the biosynthesis of amino acids and proteins [21], leading to an increase in nitrogen content in the soluble phase of the cell [17]. The high dry matter production by the tolerant genotype of quinoa appears to result from efficient utilization of absorbed nitrogen in the synthesis of organic nitrogenous compounds, thereby restricting its accumulation in the cytoplasm.

C. Ionic Distribution

Plant growth under increasing levels of NaCl results in the accumulation of Na+ and Cl- ions in various plant parts. NaCl has a well-pronounced specific ion effect on the uptake and transport of certain nutrients and ions present in the growth medium [23], [24], [35], [26]. The results of the present investigation showed an excessive accumulation of Na+ and Cl- in the root, stem, leaf sheath, and leaf blade of all genotypes. However, there was a significant difference among the genotypes in the accumulation of these ions in their various parts [18]. [13] observed a reduction in shoot and root dry weight due to the toxic effects of Na+ and Cl- ions in these parts. [14] reported a reduction in shoot and root K+ and an increase in shoot and root Na+ and Cl- concentrations. [19] found an increased content of root Na+, while petiole and stem Na+ were found to be decreased.

A. S. Bhatti *et al.,* [3] concluded that the tolerance of a cultivar was due to a high growth rate, which caused dilution of Na+ in various parts of the plants and effective partitioning of Cl- ions. They found that the leaf sheath acted as a strong sink for toxic ions, and these results were confirmed by [36].

The results of the present investigation revealed that G1 effectively transported most of its Na+ and Cl- ions to the leaf sheath, while the other three genotypes showed a higher accumulation of Na+ and Cl- in the stem, root, and leaf blade. The tolerant genotype avoided most Na+ and Cl- transport to the leaf blade and transported the majority of K+ to the leaf blade.

The tolerant genotype maintained a comparatively low Na+
+ ratio in the leaf blade and a fairly high Na+
+ ratio in the leaf sheath, followed by G2, G3, and G4. The roots of all genotypes exhibited almost similar Na+
+ ratios, except for G4, which showed a very high Na+
+ ratio at 300 mM NaCl. A similar trend was observed for the Cl-
+ ratio among all genotypes (Table 7). The results for the Na+
+ ratio in the stem showed a similar pattern across all genotypes.

However, increasing NaCl levels caused an increase in the Na+
+ and Cl-
+ ratios in the stem and leaf sheath.

The greater tolerance of G1 seems to be attributed to its ability to effectively partition toxic ions into the leaf sheath [35] and K+ to the physiologically important leaf blade [37]. Additionally, the high growth rate of G1 might contribute to Na+ and Cl- dilution due to rapid cell division.

V. CONCLUSION

It concluded that all the genotypes shown a non-significant general increase in level of stem nitrogen content. The level of nitrogen remained almost constant in G1 leaves but increased in G2, G3 and G4. All these results indicated that G1was the most salt tolerant genotype followed by G2, G3 and G4 and was most suitable for growth in areas affected by salt stress as it showed better capability to cope with such problems.

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