

EVALUATION OF SALT TOLERANCE AND YIELD PERFORMANCE OF THREE
QUINOA (*CHENOPODIUM QUINOA* WILLD.) VARIETIES UNDER SALINE
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Article Received: 07 September 2026

Article Revised: 28 September 2026

Article Published: 01 October 2026



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DOI: <https://doi.org/10.5281/zenodo.23118907>

How to cite this Article: George Gandour¹, Fadi Abbas², Hala ALAli Al Hussain^{3*} (2026). Evaluation Of Salt Tolerance And Yield Performance Of Three Quinoa (*Chenopodium Quinoa* Willd.) Varieties Under Saline Conditions. World Journal of Advance Healthcare Research, 10(10), 441–446.

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ABSTRACT

This study was conducted at the Agricultural Scientific Research Center in Homs, Syria, during the 2024 growing season. The aim was to evaluate the effect of salt stress on the productive characteristics of three quinoa varieties (NSL-106398, Red Carina, and Giza1). Four saline solutions were prepared using pure sodium chloride at concentrations of 150, 300, 450, and 600 mM, in addition to a control treatment using fresh water. The studied traits included number of flower clusters, thousand-seed weight, biological yield, seed yield, and harvest index. The experiment was designed using a randomized complete block design (RCBD) with three replications. The results revealed genetic variation among the varieties in response to salinity stress. A progressive decline in all productive traits was observed with increasing NaCl concentrations. The variety NSL-106398 exhibited the highest values across all studied indicators compared to the control, and was therefore considered salt-tolerant across different production stages. In contrast, Red Carina was classified as salt-sensitive, while Giza1 showed moderate tolerance during different growth stages.

KEYWORDS: Salt stress; Biological yield; Productive characteristics; Quinoa (*Chenopodium quinoa* Willd.).

1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) belongs to the order Caryophyllales, family Amaranthaceae (subfamily Chenopodiaceae); and genus *Chenopodium*.^[1] It is classified as a pseudocereal because its seeds are used in a manner similar to true cereals. Quinoa is an annual plant, typically reaching a height of 0.5 to 1.5 m. It has a branched taproot system that contributes to its drought resistance. The stem is thick, erect, and may be branched or unbranched. Its leaves resemble those of spinach and chard. The flower clusters, which resemble those of white corn, are borne at the tips of the branches, and the plant is largely self-pollinating. Seeds and leaves exhibit various colors, and the seeds are small, with a diameter of 2–3 mm. Quinoa maturity varies by variety: early-maturing types ripen within 100–120 days, medium-maturing types within 150–160 days, and late-maturing types may require up to 180–200 days.^[2, 3]

The high nutritional value of quinoa seeds is attributed to their rich content of proteins, essential fatty acids, minerals, and vitamins.^[4] They also contain polyphenols and flavonoids, which are beneficial to human health. Additionally, quinoa seeds can be used for oil extraction; the oil is rich in linoleic acid (omega-6) and has a fatty acid composition similar to that of corn oil. Moreover, the high fiber content in quinoa contributes to positive health effects, including lowering cholesterol levels and improving digestion.^[5]

According to the FAO statistical database (FAOSTAT): the cultivated area and total production of quinoa in the main producing countries (Bolivia, Peru, and Ecuador) increased twofold and threefold, respectively, during the period 1992–2010. In 2002, approximately 80,000 hectares were recorded as being planted with quinoa, mostly in the Andes Mountains region. The cultivated

areas in Bolivia, Peru, and Ecuador were 118,913, 64,223, and 2,214 hectares, with total productions of 65,648, 79,269, and 3,903 tons, respectively.^[6] Numerous studies worldwide have demonstrated the feasibility of cultivating quinoa as a suitable crop in drought-stricken areas^[7], under high temperature and saline conditions^[8], and in poor soils.^[9]

Reports published in the 1990s indicated that approximately 20% of agricultural land suffers from salinity problems to varying degrees, and that about 7% of the world's agricultural land is affected by salinity.^[10] This problem has now been greatly exacerbated by the deterioration of irrigation water quality, inadequate salt drainage, and other factors such as soil type, high solar radiation, and elevated temperatures. According to the Food and Agriculture Organization (FAO): saline agricultural land is increasing at a rate of 3 hectares per minute. The major challenge is that only a limited number of crops can adapt to saline conditions.^[11]

From an agricultural perspective, salinity is defined as the accumulation of dissolved salts in soil water to the extent that it negatively affects plant growth.^[12] Plant tolerance to salinity is defined as the ability to grow and complete its life cycle in an environment containing high salt concentrations. Based on this definition, plants are classified into two main groups: halophytes (salt-tolerant) and glycophytes (salt-sensitive). Halophytes can grow under high salt concentrations in the root zone, whereas glycophytes—which include most cultivated crops—cannot complete their life cycle or suffer significant productivity reductions under saline conditions.^[13]

The salinity tolerance threshold is defined as the maximum electrical conductivity (EC) of the soil that a plant can tolerate without yield reduction; beyond this threshold, productivity decreases as EC increases. Plants are classified based on their salinity tolerance into tolerant, moderately tolerant, moderately sensitive, and highly sensitive categories.^[14] Crops vary widely in their sensitivity to salinity. Most crops are sensitive even when soil EC is below 3 dS m⁻¹.^[15] In contrast, quinoa is known for its high salt tolerance, with a threshold up to 14.5 dS m⁻¹, and some genotypes can withstand up to 40 dS m⁻¹. However, quinoa's sensitivity to salinity varies with growth stage; the germination stage is more sensitive than later stages, and tolerance generally increases with plant age.^[16, 17]

A study by Abo-Kassem^[18] tested six salinity levels for 70 days on the quinoa variety 'Titicaca' and found a significant inhibitory effect on seed germination only at the higher concentration of 400 mM NaCl, while optimal plant growth was achieved between 100 and 200 mM NaCl. In general, salt stress in sensitive quinoa varieties leads to ion toxicity and osmotic stress, negatively affecting plant physiology, growth, and development. Salinity also disrupts cytoplasmic enzyme activity and

may cause oxidative damage and nutritional imbalances, ultimately leading to significant yield reductions.^[19]

Studies on the ability of quinoa to survive and produce under stress conditions are still limited and inconclusive. In Syria, quinoa research remains in the experimental stage, although the General Commission for Agricultural Scientific Research has recently begun to focus on this crop, with promising initial results. To further investigate quinoa's stress tolerance in potential cultivation areas, including saline soils in the eastern regions, it is necessary to study the adaptation of introduced quinoa varieties to local environmental conditions and their ability to tolerate salt stress. Based on the above, this research aims to evaluate the response of three introduced quinoa varieties to salt stress by studying the effect of sodium chloride on some yield-related indicators.

2. MATERIALS AND METHODS

2.1. Experimental Site and Soil Preparation

The field experiment was conducted at the General Commission for Agricultural Scientific Research, Homs Research Center, during the 2024 growing season. Three quinoa varieties were studied: NSL-106398, Red Carina, and Giza1. Prior to soil preparation, soil samples were analyzed. The results indicated that the soil was clayey with an alkaline pH (8.1): medium nitrogen content (0.35%): rich in phosphorus (25 ppm): and medium potassium content (320 ppm). Meteorological data during the experiment were recorded, with average temperatures ranging from 18°C to 32°C and relative humidity between 45% and 65%.

2.2. Pot Preparation and Planting

A homogeneous soil mixture was prepared by mixing two-thirds red soil with one-third sand (obtained from the study site's clayey-sandy soil). The sand was thoroughly washed to remove salts, dried, and then mixed with the soil. The mixture was blended until homogeneous and packed into black polyethylene bags (36 cm height × 25 cm diameter). Ten seeds were sown per bag at a depth of 2 cm. After sterilization, the pots were lightly irrigated immediately after planting and again a few days later to ensure complete germination. Subsequent irrigation was applied as needed to maintain soil moisture at approximately 70% of field capacity. Thinning, weeding, and pest control were carried out equally across all experimental pots at appropriate times. Sodium chloride treatments were applied three weeks after germination, and harvesting was conducted on June 25, 2024.

2.3. Salt Treatments

Four saline solutions were prepared using pure sodium chloride at concentrations of 150, 300, 450, and 600 mM, in addition to a control treatment using fresh water (0 mM). Each treatment was applied to the pots according to the experimental design. Saline solutions were added in equal volumes to avoid differential leaching effects.

2.4. Studied Productive Characteristics

After the completion of the flowering stage, three plants from each concentration were randomly selected from each replicate to estimate the following productive characteristics:

- Number of flower clusters per plant.
- Thousand-seed weight (g): calculated by weighing 1000 seeds from three samples per plot and computing the average.
- Biological yield (g plant⁻¹): total dry weight of the entire plant.
- Seed yield (g plant⁻¹): weight of seeds per plant.
- Harvest index (%): calculated as (seed yield / biological yield) × 100.

2.5. Experimental Design and Statistical Analysis

The experiment was designed as a randomized complete block design (RCBD) with three replications. Analysis of variance (ANOVA) was performed for all studied traits, and the least significant difference (LSD) was calculated at a probability level of 0.05. Mean comparisons were performed using the LSD test at a 5% probability level. All statistical analyses were conducted using SPSS software (version 26.0, IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSION

3.1. Effect of Sodium Chloride on Number of Flower Clusters

As shown in Table (1): significant differences ($P < 0.05$) were observed in the number of flower clusters among the studied varieties treated with NaCl solutions. The overall averages for the varieties Red Carina, NSL-106398, and Giza1 were 4.96, 6.36, and 5.54, respectively. With increasing salt concentrations (150, 300, 450, and 600 mM): the average number of flower clusters decreased progressively, recording 7.37, 5.97, 4.07, and 2.47, respectively, compared to 8.23 in the control. The varieties NSL-106398 and Giza1 showed higher numbers of flower clusters at low concentrations compared to Red Carina; however, this advantage diminished as salt concentrations increased. The reduction in flower cluster number may be attributed to inhibited vegetative growth, hormonal imbalance, osmotic stress, ion toxicity, and a shortened growth period, all of which reduce flower bud formation. Furthermore, salinity-induced changes in phytohormone levels, particularly abscisic acid (ABA) and cytokinins, are known to inhibit floral initiation and development.^[30] These findings are consistent with those of Hayat et al.^[30]

Table 1: Effect of sodium chloride on number of flower clusters.

NaCl Concentration (mM)	Giza-1	NSL-106398	Red Carina	Average
0	7.70	8.30	8.70	8.23
150	7.00	7.60	7.50	7.37
300	6.30	6.30	5.30	5.97
450	4.60	5.30	2.30	4.07
600	2.10	4.30	1.00	2.47
Average	5.54	6.36	4.96	—
LSD 0.05	V = 1.11, S = 1.48, V×S = 2.02, CV = 2.9%			

3.2. Effect of Sodium Chloride on Thousand-Seed Weight (g)

Significant differences ($P < 0.05$) were observed in thousand-seed weight among the studied varieties (Table 2). The overall averages for Red Carina, NSL-106398, and Giza1 were 2.43, 2.63, and 2.36 g, respectively. With increasing salt concentrations, thousand-seed weight decreased progressively, recording 2.67, 2.51, 2.35, and 2.13 g at 150, 300, 450, and 600 mM, respectively, compared to 2.72 g in the control. The varieties NSL-106398 and Giza1 showed higher thousand-seed weights at low concentrations compared to Red Carina. The decrease in thousand-seed weight is

attributed to poor seed filling due to reduced photosynthesis, lower carbohydrate and protein reserves, and a shortened growth period resulting from osmotic stress, ion toxicity, and oxidative stress. The accumulation of Na⁺ and Cl⁻ ions in source leaves accelerates chlorophyll degradation and reduces photosynthetic efficiency, limiting assimilate supply to developing seeds.^[23] These results are consistent with Peterson and Murphy^[31], who observed significant decreases in thousand-seed weight of quinoa under salinity.

Table 2: Effect of sodium chloride on thousand-seed weight (g).

NaCl Concentration (mM)	Giza-1	NSL-106398	Red Carina	Average
0	2.57	2.79	2.81	2.72
150	2.55	2.75	2.71	2.67
300	2.41	2.71	2.41	2.51
450	2.22	2.61	2.21	2.35
600	2.05	2.31	2.01	2.13
Average	2.36	2.63	2.43	—
LSD 0.05	V = 0.06, S = 0.09, V×S = 0.14, CV = 3.9%			

3.3. Effect of Sodium Chloride on Biological Yield (g plant⁻¹)

Significant differences ($P < 0.05$) were observed in biological yield among the studied varieties (Table 3). The overall averages for Red Carina, NSL-106398, and Giza1 were 60.09, 67.88, and 57.34 g plant⁻¹, respectively. Biological yield decreased progressively with increasing salt concentrations, recording 71.99, 64.31, 54.94, and 42.30 g plant⁻¹ at 150, 300, 450, and 600 mM, respectively, compared to 75.31 g plant⁻¹ in the control. The varieties NSL-106398 and Red Carina showed higher biological yields at low concentrations.

The reduction in biological yield is attributed to limited water availability, reduced photosynthetic efficiency, decreased chlorophyll concentration, lower number of productive branches, and reduced fertility rate. The observed reduction in biological yield under salinity stress could be attributed to the accumulation of Na⁺ and Cl⁻ ions in plant tissues, which disrupts photosynthetic electron transport and reduces CO₂ assimilation. Additionally, salinity-induced stomatal closure limits CO₂ diffusion, further decreasing photosynthetic rates and biomass accumulation.^[19, 23] These findings are consistent with Ali et al.^[32]

Table 3:. Effect of sodium chloride on biological yield (g plant⁻¹)

NaCl Concentration (mM)	Giza-1	NSL-106398	Red Carina	Average
0	73.36	75.25	77.32	75.31
150	69.36	74.25	72.36	71.99
300	60.36	70.21	62.36	64.31
450	50.36	64.36	50.10	54.94
600	33.25	55.32	38.32	42.30
Average	57.34	67.88	60.09	—
LSD0.05	V = 6.22, S = 8.56, V×S = 14.11, CV = 4.1%			

3.4. Effect of Sodium Chloride on Seed Yield (g plant⁻¹)

Significant differences ($P < 0.05$) were observed in seed yield among the studied varieties (Table 4). The overall averages for Red Carina, NSL-106398, and Giza1 were 12.34, 15.61, and 11.83 g plant⁻¹, respectively. Seed yield decreased progressively with increasing salt concentrations, recording 16.97, 13.68, 10.59, and 7.29 g plant⁻¹ at 150, 300, 450, and 600 mM, respectively, compared to 17.76 g plant⁻¹ in the control. The variety NSL-106398 showed the highest seed yield across all concentrations. The reduction in seed yield is attributed

to insufficient water availability due to increased salt accumulation in the root zone, which negatively impacted plant growth. The superior performance of NSL-106398 may be related to its ability to maintain higher K⁺/Na⁺ ratios in leaf tissues, better osmotic adjustment through compatible solute accumulation (such as glycine betaine and proline): and more efficient reactive oxygen species (ROS) scavenging systems.^[24] These results are consistent with Hussain et al.^[24], Rezzouk et al.^[33], and Munns et al.^[28]

Table (4). Effect of sodium chloride on seed yield (g plant⁻¹)

NaCl Concentration (mM)	Giza-1	NSL-106398	Red Carina	Average
0	16.32	18.32	18.63	17.76
150	15.54	18.05	17.32	16.97
300	12.36	16.36	12.32	13.68
450	9.36	14.21	8.21	10.59
600	5.55	11.10	5.21	7.29
Average	11.83	15.61	12.34	—
LSD 0.05	V = 1.21, S = 1.68, V×S = 2.38, CV = 3.4%			

3.5. Effect of Sodium Chloride on Harvest Index (%)

Significant differences ($P < 0.05$) were observed in harvest index among the studied varieties (Table 5). The overall averages for Red Carina, NSL-106398, and Giza1 were 19.55%, 22.82%, and 20.08%, respectively. Harvest index decreased progressively with increasing salt concentrations, recording 23.55, 21.18, 19.02, and 16.78% at 150, 300, 450, and 600 mM, respectively, compared to 23.56% in the control, representing reductions of 0.04%, 11.23%, 23.86%, and 40.40%, respectively. The variety NSL-106398 showed higher harvest index values at low concentrations. The decrease

in harvest index is attributed to difficulty in water absorption under salinity, which reduces cell expansion and photosynthesis, thereby decreasing the total energy available for grain formation and reducing the conversion of vegetative mass to seed yield. The relatively higher harvest index of NSL-106398 under salinity suggests better assimilate partitioning toward reproductive organs, which is a key trait for salt tolerance in grain crops.^[27]

These results are consistent with Richards.^[27]

Table (5). Effect of sodium chloride on harvest index (%)

NaCl Concentration (mM)	Giza-1	NSL-106398	Red Carina	Average
0	22.25	24.35	24.09	23.56
150	22.40	24.31	23.94	23.55
300	20.48	23.30	19.76	21.18
450	18.59	22.08	16.39	19.02
600	16.69	20.07	13.60	16.78
Average	20.08	22.82	19.55	–
LSD 0.05	V = 1.12, S = 1.36, V×S = 1.54, CV = 4.3%			

4. CONCLUSIONS AND RECOMMENDATIONS

1. Increasing the concentration of saline solution in the growing medium leads to a progressive decline in all productive characteristics (number of flower clusters, thousand-seed weight, biological yield, seed yield, and harvest index) of quinoa under field conditions.
2. The response of the tested varieties varied according to their salt tolerance during different growth stages. Based on the results, the variety NSL-106398 demonstrated superiority over the other studied varieties and was classified as salt-tolerant, while Red Carina was classified as salt-sensitive, and Giza1 showed moderate tolerance.
3. The superior performance of NSL-106398 under salinity stress suggests that this variety possesses efficient ion exclusion mechanisms, better osmotic adjustment, and effective ROS scavenging systems, making it a promising candidate for cultivation in saline-affected areas.

Based on the above, we recommend

- Conducting further studies focusing on ion transport mechanisms to better understand salt tolerance in quinoa.
- Evaluating physiological and biochemical markers (such as proline accumulation, antioxidant enzyme activity, and K^+/Na^+ ratio) to facilitate rapid screening of salt-tolerant genotypes.
- Testing additional quinoa varieties under field conditions across multiple seasons to confirm the stability of salt tolerance.
- Expanding quinoa cultivation in saline-affected regions of Syria (such as eastern areas) to improve food security and sustainable agriculture.

5. ACKNOWLEDGMENTS

The authors would like to thank the General Commission for Agricultural Scientific Research, Homs Research Center, for providing the necessary facilities, materials, and technical support for this study. Special thanks to the technical staff for their assistance during the field experiment and data collection.

6. Conflict of Interest

The authors declare no conflict of interest.

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