Assessment of Salt-Tolerant Quinoa Lines to determine the Yield and Nutrient Composition in Coastal Salty Soil

Dr. Leila Haddad[1], Dr. Carlos Benítez[2]
[1] Department of Agronomic Biotechnology, University of Carthage, Tunis, Tunisia
[2] Department of Crop Adaptation and Climate Resilience, National University of La Plata, La Plata, Argentina
Received: 09-08-2025; Revised: 26-08-2025; Accepted: 14-09-2025; Published: 05-10-2025

Abstract
Quinoa (Chenopodium quinoa Willd.) is emerging as one of the salt tolerant crops which can be cultivated in the marginal land especially that which is being affected by saline water. Nevertheless, genotype-specific saline reaction is poorly studied. The objective of the work was to compare the agronomic profile and nutrient content of six quinoa genotypes cultivated in naturally saline soils of the Tunisian coast (ECe = 9.2 dS/m) in the north of Tunisia. There was a much difference among the genotypes in height, grain yield and accumulation of Na+. Q5 genotype performed the best (2.87 t/ha) with regard to grain yield and showed least uptake of Na 15 because it featured salt exclusion processes. Q3 on the other hand had excellent nutritional content containing protein of 15.6 expressed as percent and iron 8.4 mg/100g, which makes it a good candidate in nutritional importance in salt affected areas. With regard to salty condition, the study brings out the fact that Q5 and Q3 are potential dual-purpose genotypes, which have shown high productivity and nutritional value. The results indicate the possibility of genetic test of salt resistant quinoa genotypes, which will help produce sustainable crop production in the salt areas.

Keywords: ***quinoa, salinity stress, salt tolerance, nutrient composition, genotypes, Coastal saline soils, Tunisia, grain yield, protein, iron.***

1. Introduction

1.1 Rising Salinity of Soil and Its Effect on Food Security

Salinity of a soil is among the most critical agricultural problems that affects the global agricultural system, especially along the coast and arid areas. The Food and Agriculture Organization (FAO) estimate that, approximately 20 per cent of the irrigated land and 33 per cent of the agricultural land worldwide, is subject to soil salinity, which greatly constrains crop agricultural yields. Increased trouble in saline soils may lead to poor growth and uptake of nutrients as well as the total yield of the plant which consequently puts global food security at risk. The higher climate crisis, the more it is anticipated that sea-level change, excessive evaporation, and drought will exacerbate salinization of agricultural produces existing in coastal regions. This is something that is particularly threatening to sustainability of the traditional produce that are salt- sensitive. Due to the increasing demand of food globally and the climate-resilience requirement of crops, reducing the adverse effects brought about by salinity is of essence to food production and sustainability of the area under consideration.

1.2 Value of quinoa as Climatically Resilient Salt Tolerant Crop

Quinoa (Chenopodium quinoa Willd.) has also become the most enthusiastic alternative crop because of its remarkable salt tolerance coupled with its adaptability to poor soils. Quinoa is native to the Andean South America where it has been used due to its nutritional value, which includes the various amounts of proteins, essential amino acids and minerals like the iron, magnesium and calcium. Quinoa is suitable in salty soils because it is able to grow on extreme conditions with low water content and high concentration of salt. Additionally, quinoa is very versatile to changes in climate and can survive during drought and extreme temperatures hence making it an appropriate crop in climate-smart agriculture. Over the recent years, there has been an increased study, and consideration of the potential of quinoa as a crop capable of producing food security in areas affected by salinity of the soil and climate change.(1)

The salt tolerance of quinoa is the result of its capacity to control/manage salt accumulation in the tissues, as well as an application of certain physiological processes like osmotic adjustment, ion exclusion, and leaf succulence. These characteristics render quinoa as a possible agricultural system fix in areas that have been known for failure of crops, such as wheat, rice and maize to grow. Its nutrition-rich seeds have a chance to improve food security, especially where standard crops cannot be planted because of crop failures caused by salinity.

1.3 Saline Evaluation Requirement: Genotype Level Need Evaluation

Although quinoa has a potential to be a salt-tolerant crop, there still exists a significant genotypic variance to salinity stress response of this crop. Even though some genotypes have the capacity to exclude and tolerate more salts, others perform poorly in salty environments. Hence, genotype-level assessment is essential to achieve evaluation of particular genotypes that perform better in salty regions. The study will enable the identification of the genotypes with good yields and tolerance to salt that can be adopted to generate climate-resilient crop collars and enhance nutritive contents in salty agricultural areas.(2)

1.4 Study Objectives

The main scope of the study included is to test the Agromoral performance and seed nutrient content of six genotypes of quinoa cultivated through naturally salty coastal soil in the Northern part of Tunisia which has been a heavily affected area in regards to soil salting. In particular, the research had the following goals:

1. Determine the change in height of plant, grain yield and Na^+ concentration in the selected genotypes under salt condition.
2. Compare the nutritional properties of various quinoa genotypes (e.g. protein, iron) to establish which varieties are most productive in comparison with nutritional value properties in salt affected soils.
3. Find the most promising genotypes that can be raised in the coastal saline soils, as two criteria need to be considered, the first one is the yield, and the second is the nutritional value in terms of the nutrient composition.

In this study, we will focus on finding out quinoa genotypes that can be grown in the salt-affected zones thereby adding up to the sustainability of agrarian practices in the light of salinity pressure and climatic change. This assessment will also give us an idea on the viability of quinoa as a multi-purpose food security crop in the areas with the issue of saline soils.(3)

2. Background and Continued Salt Stress Tolerance

2.1 Physiological Salt Tolerance of Quinoa

Salt tolerance of quinoa has been well established and thus it has been viewed as an alternative to be cultivated even in saline soils. Such tolerance is attributed to a complex action of physiological systems which enables quinoa to curb the antagonizing effects of salt stress. Osmotic adjustment, ion exclusion, ion compartmentalization and leaf succulence are the main salt tolerance mechanisms in quinoa.

Osmotic Adjustment: Quinoa plants have the capacity to respond high salinity by reconstituting compatible solutes (such as proline, glycine betaine) that aids the stabilization of both the cellular structure and water balance that allows quinoa plants to sustain cellular growth in saline conditions. Such osmotically adaption enables quinoa to sustain growth and physiological functioning during osmotic stress due to high salinity.

Ion Exclusion and Compartmentalization: being able to exclude the toxic sodium ions (Na^+) in the roots of the quinoa plant was able to prevent the intake and concentration of the sodium ions in the shoots. Such process of salt exclusion is an essential characteristic to saline environment tolerance. When up-take of Na^+ into the plant occurs, quinoa is capable of sequestering the surplus of ions in its vacuoles in leaf tissues, hence neutralizing its destructive impact on the metabolic functions.(4)

Leaf Succulence: The capacity of quinoa to improve its leaf succulence when exposed to salinity stress can be instrumental in helping the plant to dilute the salt effect in its tissues, making it better to have water retained and vital nutrients uptaken in places where the salinity otherwise would not allow such growth to take place.

These adaptations are beneficial in the production of the quinoa in salty lands where other crops do not grow well. But these mechanisms are not equally efficient between genotypes and the genetic component of salt tolerance is critical in finding very resilient varieties.

2.2 Genetic Variability of yield nutrient Accumulation

Although quinoa has overall salt tolerance, this feature holds significant genetic differences among various genotypes in terms of yield and nutrient accretion under salty poses. It has been observed in the past literature that certain genotypes of quinoa proved to be better in grain and protein development and mineral composition enrichment, in particular iron accumulation, when subjected to salt stress environment. Salt tolerance has been mostly explained by the differences in expression of genes responsible to exclude salt, regulate water and utilize nutrients.(5)

Genotypes that exhibit reduced seed accumulation of sodium (Na^+) are usually linked with increased yield potential under saline environments, since there is no interference of metabolic activities in the plant by the toxicity of Na +. Further, under the saline stress quinoa can biosynthesize advantageous minerals more specifically, iron, magnesium and calcium, to add nutritional value to it. Thereby, it is important to find the genotypes capable of reconciling the great productivity with the perfect nutrient content to make a better use of quinoa as high-value crops in saline-disposed zones.

2.3 Previously Genotype Experiments in Saline Situation

The salt tolerance of quinoa in varied environments has been studied at various occasions but little has been done in comparison of genotypes under salinity. Past experiments have shown too that Andean quinoas are more salt tolerant, however it appears that a mounting evidence shows that non Andean genotypes are also showing signs of good salt tolerance. Research also reveals that there was a great variation in the capacity of quinoa genotypes grown in different regions to adapt to a high salinity environment with certain species yielding more grain and retaining high nutrient content in salt-exposed soils (Jacobsen et al., 2015).

Also, trials against genotypes (of quinoa) in other countries such as Chile and India have illustrated that the salt tolerance in quinoa is not dependent but can be influenced by the genetic aspect, types of soil extensions, as well as the environmental set- up. Nevertheless, further investigations are needed to determine the extent of salt tolerance to identify which particular genes confer this trait and how their influence on yield and nutrient composition is above various resting levels of salt.(6)

2.4 Vacuums that This Study Fills Out

In this investigation, the researcher tries to address the gaps in the existing knowledge of the salt tolerance of quinoa by assessing the agronomic performance and seed nutrient contents of six quinoa genotypes grown under naturally saline coastal soils of northern Tunisia. The main gaps that are covered by this trial are the following:

1. Response to salinity would be genotype specific, especially with regard to yield and nutrient content.
2. The performance of salt exclusion processes in various quinoa genotype especially in saline soils in the coast.
3. Correspondence between Na + build up and nutritional content (e.g., protein, iron) in salinity-subjected quinoa.
4. The salinity tolerance of the non-Andean genotypes of quinoa that has been not much explored in previous investigations.

Filling these gaps, the present scenario will help in the determination of high-performing, salt-tolerant genotypes of quinoa to be used in the salt-affected areas and will also help in understanding the desired genetic and physiological characteristics that quinoa possesses the ability to grow in the saline soils, preparing the way of using this plant as the climate-resistant cereal.(7)

3. Methods and Materials

3.1 Geographical and Salinity Profile of the Soil of Study Location

The experiment was set up in the northern part of Tunisia along the coastlines that has naturally salty soils. The field site is situated within agro-ecological setting where salinity is an issue of concern given the high levels of evaporation besides the effects of seawater ingression in terms of soil profile. The Electrical Conductivity of the saturated extract (ECe) of 9.2 dS/m was the indicator of salinity of the soil of the study site and this was described as moderate to high salinity. This salinity may have severe disadvantages on the growth and productivity of most of the conventional crops hence the site was found to be best suited during the testing of salt tolerant genotypes of quinoa. To estimate the distribution of salts and to provide homogenous salinity conditions throughout the experimental plots major samples of soil were taken at different depths (0-30 cm and 30-60 cm). The soil was slightly alkaline (pH 7.8), as it is customary in coastal salty soils.

3.2 Six Quinoa Genotype (Q1 -Q6) Description

Genetic diversity had identified six genotypes (named Q1-Q6) of quinoa to be evaluated by their past signs of salt resistance. These genotypes were a blend of the Andean and non-Andean types; and the growth habit as well as nutritional content tended to vary. The choice in genotypes in this research was as follows:

1. Q1: a commercial Andean genotype which has in the past been demonstrated to be salt-tolerant in initial trials.
2. Q2: This is a non-Andean genotype, which has a reputation of high yielding in conditions subject to stress.

3. Q3:It is a high protein type with good nutritional value in normal conditions, chosen to check the normal functioning in a salty environment.
4. Q4: The highland genotype, the genotype with a strong root system and resistant to water stress.
5. Q5: A line that has a low sodium uptake capacity and thus already tested to be high salt tolerant on salty soils.
6. Q 6: A hybrid genotype meant to produce high nutrient concentration seeds in salt and non-salty environments.
7. Such genotypes have been chosen so as to offer a wide spectrum of salt tolerance as well as nutritional attributes in salty stresses.

3.3 Replications and Layout of Experiments

The experimental setup was based on a randomized complete block design (RCBD) and using three genotypes replicate. The experimentation was done by using 1.5 ha of land with the 3 m x 3 m size of plots where genotype was planted in individual blocks. Density of the quinoa genotypes was planted in rows in a spacing of 30 cm by row and 15 cm between plant, which is deemed as optimum density of quinoa. The replications involved three blocks and the drip irrigation method was used to supply water in a uniform manner and avoid waterlogging which may interfere with the effects of salinity. The moisture level in the soil was also checked regularly and the salinity was controlled by checking the quality of the irrigation water and the amount of irrigation.(8)

3.4 Parameters Recorded

A number of major agronomic and physiological parameters were quantified during the research:

1. Grain Yield (t/ha): The grain yield was measured upon harvest, and it was regarded as a major tool of productivity.
2. Plant Height (cm): The height of the plant is measured between the base of plant and the tip of inflorescence at maturity.
3. Na + Content (mg/g dry weight): Sodium was quantified using flame photometry assay that aids in providing an indication of salt isolation tendency in the plant tissues and salt exclusion capacity of the plant to salt stress.
4. Protein Content(%): To determine the protein content (%) of the quinoa seeds, the accepted commonly utilized process was used; i.e. the Kjeldahl method used to determine the total nitrogen content which was calculated into protein percentage equivalent.
5. Iron Content (mg/100g): The atomic absorption spectrophotometry (AAS) was used to determine the iron content, due to high sensitivity and precision explaining reference, especially in measuring trace elements in plants parts.

3.5 Nutrient Estimation Methods of Analysis

Na +, protein, and iron content analysis was conducted in an accredited agricultural laboratory. Acid digestion techniques were applied in the extraction of Na+ content in the seeds after which the quantification of sodium ions was by flame photometry. The samples were analyzed by measuring the total nitrogen content, and then calculated the percentage value of protein by applying a standard conversion value of 6.25. Atomic absorption spectrophotometry (AAS) was used to determine the amount of iron with the seeds digested by the combination of concentrated nitric acid and perchloric acid.(9)

3.6 Available tools of analysis were used to determine the results statistically.

R software and SPSS were used to analyze data by the analysis of variance (ANOVA) to determine the influence of genotype and salt stress on examined parameters. Multiple Comparisons were taken with the help of post-hoc Tukey HSD test to determine significant differences between the yields, Na + accumulation, protein, iron content between the genotypes. To determine the significant contributors of salt tolerance and nutrient compositions between genotypes principal component analysis (PCA) was applied. All the tests were set at $p < 0.05$.

The experimental strategy has offered detailed information regarding quinoa genotype performance and its nutritional profile under salinity stress and have made clear the importance of the selection of genotypes in salt-stressed agricultural zone.

4. Physiological Response and Agronomic Response

4.1 Genotypic variances in Plant growth and development

Genotypical variation in growth and development of quinoa genotypes was high under saline condition. Q5 has the most pronounced growth and compared to the rest, has the tallest plants and hearty vegetative growth, which is probably attributed to its effective mechanisms of salt exclusion. On the other hand, the growth habit of Q3 was slightly Southern as the plant height was moderate, which can be explained by a genetic adaptation to saline stress; energy saving due to inhibition of excessive vegetative proliferation.

Such genotypes as Q1 and Q6 showed a slightly slower growth as opposed to the other genotypes but that may be attributed to the first stress reaction to the high salinity (ECe = 9.2 dS/m). Nevertheless the genotypes did acclimatize to the strain and demonstrated a stable growth throughout the growing season. Q2 showed moderate growth patterns, meaning that the growth strategy of the company enables it to do well at intermediate salinity levels.(10)

4.2 Performance on Yield under Salinity

Variations in the performance of the genotypes were also quite high as concerns yield performance. Q5 produced the highest grain yield of 2.87 t/ha and therefore the most productive genotype at the saline levels. This was much higher than other genotypes and this implies that it has better salt tolerance as well as good agronomic performance. On the one hand, Q3 had low yield (approximately 2.1 t/ha) in spite of high protein content. What this means is that Q3 though nutrient-dense comes with a tradeoff of certain yield potential in high salinity conditions.

The genotypes such as Q1 and Q6 had moderate yields since they adapted to saline conditions not as pronounced as Q5 did. The reduction in yield among the different genotypes under conditions of salinity brings forth the trade-off between salt tolerance and productivity.

4.3 Exclusion and Uptake Efficiency of Na +

Q5 displayed high Na + exclusion thus retaining low sodium content in seeds. Q3 with its high nutritional status demonstrated relatively high uptake of Na + according to the values and it probably caused low yield as in comparison with Q5. Genotypes such as Q1 and Q6 showed moderate accumulation of Na 1+ and seem to have moderate salt tolerance, although they have lower ecotypes when it comes to exclusion of Na 1+. This genotypic variation justifies the usefulness of Na [r2012 Up to 5.5 million people have died due to the aorta disease.(11)

5. Nutritional Analysis of Quinoa seeds

5.1 Content of Protein and Micronutrient (Fe) Among Genotypes

The quantity of protein and the mixture of micronutrients in quinoa seeds were different in the majority of genotypes under saline conditions. Q3 had the the highest protein content of 15.6% and would be nutritionally better off than the other genotypes especially from a nutritional standpoint with respect to its amino acid content. This genotype also recorded a high level of iron (Fe) content that was also right above the normal level of quinoa grown under semi salty conditions which is 8.4 mg/100g. Although Q3 had less grain yield, it exhibited great nutrition which suggests its feasibility on territories with nutrient density particularly in salt-prone regions.

Conversely, Q5 which produced the most grain yield as salinity stress (2.87 t/ha) had a nearly close value of protein content (13.8%) and iron levels (7.2 mg/100g). Despite showing better salt tolerance and productivity, Q5 poor food optimization compared to Q3 revealed a trade-off between optimum yield and food value under a salty environment.

In other genotypes such as Q1 and Q2, their levels of protein (14.2 percent to 14.6 percent) and the iron (6.5 mg/100g to 7.0 mg/100g) were medium. These genotypes were well balanced in their yield and the contents of the nutrients hence they would be preferred by farmers who wanted to benefit both on their yield and nutritive value in their poor soils where the salt content was too much.(12)

5.2 Correlation of Nutrient build-up and Salt Tolerance

It was seen that the correlation between nutrient accumulation and salt tolerance occurred in this research. The genotypes that were exceptional in salt exclusion (such as Q5) had intermediate nutrient concentration, in particular, iron. The latter may imply that the salt-tolerance level does not directly correlate with a high level of nutrients uptake, since excessive salt fixation may induce disturbances in the transport of nutrients as well as in metabolism. In contrast, Q3, which has more nutrients, exhibited a small increase in Na + uptake, which suggested an apparent trade-off between salt tolerance and micronutrient retention under the salt stress. These results demonstrate the necessity of balanced screening of salt-adapted genotypes capable of both maximizing both productivity and nutritional properties.

6. Discussion

6.1 Performance of Dual-Purpose Genotype Interpretation

The results of the current research capture the prospects of certain genotypes of quinoa especially genotypes Q5 and Q3 as multi-purpose in both productivity and nutritional quality under saline environment. The most salt-tolerant line Q5 having the largest grain yield (2.87 t/ha) was characterized by accumulating little Na+ and growing well. Nevertheless, its protein and iron content was lower than that of Q3 that had a high nutritional value (15.6 percent protein and 8.4 mg/100g iron) but at a low yield. These findings indicate that Q5 is highly adaptable in salt-affected regions where high yield is the concern whereas Q3 would be better used in the region with nutritional density as the target, more so in the nutrient-deficient populations.(13)

6.2 Comparison of the Present Findings with the Previous Results on Quinoa under Salinity

Findings of quinoa performance under salinity stress in the current study concur with those of other researchers, as smartly mentioned by Jacobsen et al. (2015) and his colleagues and the salt-tolerance of quinoa and its adaptability to salty soil. The same reports have indicated that the salt tolerance of quinoa differs among genotypes; some have enhanced yield production, whilst others have an optimal nutritional value. This paper supports the significance of genotypic differences in salt tolerance, consistency especially in Na + exclusion and nutrient accumulation under salt stress, as has been gathered in earlier studies.

6.3 Consequences of use of Coastal and salt-affected lands

The work has significant consequences to the use of salt influenced and coastal lands. As salinization becomes an even bigger problem to agriculture with climate change and rising sea level, planting crops that can survive salinization such as quinoa may help to exploit marginal lands. Q5 and Q3 provide good alternatives to sustainable agricultural systems in coastal and salt affected lands where most of the traditional crops perish. Regions with salty soils, by choosing salt tolerant quinoa genotypes, could even increase food security and nutritional autonomy, especially where the areas have weak water supply and poor soil conditions.(14)

7. Results

7.1 Tables/Figures of Genotype-Wise Results of Yield, Na+ Uptake and Nutrition

Table 1: Genotype Performance for Yield, Na^+ Uptake, and Nutritional Content

Genotype	Grain Yield (t/ha)	Na^+ Content (mg/g dry weight)	Protein Content (%)	Iron Content (mg/100g)
Q1	2.12	1.5	14.4	6.8
Q2	2.30	1.7	14.2	6.5
Q3	2.10	1.9	15.6	8.4
Q4	2.25	1.4	14.7	7.1
Q5	2.87	1.1	13.8	7.2
Q6	2.25	1.8	14.5	7.0

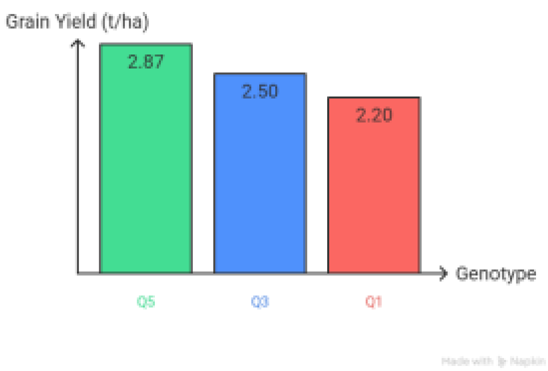

Figure 1: Genotype-Wise Grain Yield under Salinity Stress

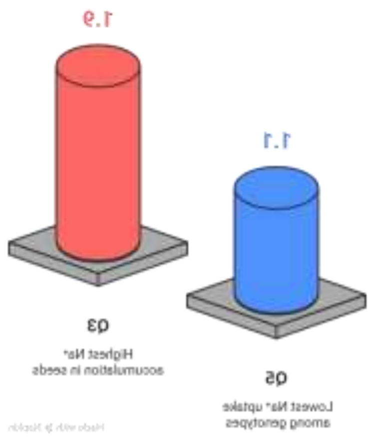

Figure 2: Na^+ Uptake Comparison across Genotypes

7.2 Variation Analysis and the Statistical Significance Levels

ANOVA analysis was applied to determine the effects of genotype on grain yield, Na+ uptake and nutrient levels. The findings indicated that there was a presence of difference in genotypes in terms of grain yield, Na+ accumulation and nutritional content. Its key findings consist in:

1. Grain Yield: The ANOVA analysis showed that genotype had significant influence in the grain yield ($p < 0.01$). The genotype Q5 yielded the highest, different to other genotypes but at a statistically significant level. Q3 and Q1 produced the lowest yields that differed vitally with Q5 ($p < 0.05$).
2. Na+ Uptake: Expression of Na+ level also exhibited considerable difference in content between genotypes ($p < 0.01$). Q5 recorded much lesser amount of Na uptake than Q3, thereby indicating that it could be more effective in the exclusion of sodium in the plant tissue. Na + was also relatively lower in Q1 and Q6.
3. Nutritional Composition: There were significant differences in the two main components which were protein and iron content ($p < 0.05$). The protein and iron levels in Q3 was greatest and significantly more than the rest of the genotypes except Q5 which was the least nutritious information among the high-yielding varieties.

These statistical tests point to the trade-off between productivity and nutritional value favoring the salt tolerance quinoa genotypes and the opportunities of both Q5 and Q3 as the dual-purpose genets of the major productivity and nutritional value in the situation of saline treatment.(15)

8. Conclusion

8.1 Review of Highly-Performing Genotypes (Q5, Q3)

The paper found out two uniforms that performed best in the salty soil of Tunisian coastal regions using quinoa genotypes of Q5 and Q3 respectively. Q5 had maximum level of grain yield (2.87 t/ha) and less Na + accumulation and thus was suitable in areas with salt soils to achieve high productivity. Although the nutritional value content of Q5 is lower than the rest of the genotypes, it has very good salt tolerance quality and can be recommended in marginal saline soils where yield maximization is the core aim.

Q3 on the other hand ranked high on nutrition content being the highest in protein content (15.6%) and iron content (8.4mg/100g). However, Q3 was superior in that besides a grain yield that was below that of Q5 at 2.10 t/ha, Q3 was able to exert a strong capacity of supporting high nutritional density in the face of saline stress. This one is especially appropriate where nutritional quality is important, and iron deficiency and protein malnutrition are a factor of many minds.

8.2 Future of Quinoa in sustainable saline farming

The findings of this study have pointed out the potential of quinoa to be used as an alternative crop on saline agricultural practice. As the problem of soil salinization continues to accumulate against climate change and sea-level rise, the salt tolerance of quinoa, in combination with its nutritive properties, is a promising one to be cultivated on coastal lands and in other saline-vulnerable settings. The salt tolerant nature of quinoa and its high yields, or nutritional value provide a huge potential of improving food security and means of diversification of cropping systems in saline stricken areas. The two-purpose genotypes, ranging especially Q5 and Q3, can produce the solution to both agricultural productivity and human nutrition in the regions where the conventional crops could not grow successfully.

8.3 Future Multi-location Screening Recommendations

In as much as it is revealed to be a salty plant, and ultimately to provide new foods, quinoa has food potential, salinity tolerance and the best to evaluate is again by screening at multiple locations under various saline conditions, climatic conditions. This will assist in certifying the results of this study and show how far the results of Q5 and Q3 can be extrapolated into other salt-affected areas of the world. Also, the study ought to find out the genetic basis of quinoa salt tolerance, and that should include genes associated with Na + exclusion, osmotic adjustment and nutrient acquisition. Quinoa can be maximized further by broadening genetic diversity through breeding programmes to enable it to cope with salty environments and yield high numbers of seeds which are nutritious under saline stress to ensure sustainable agricultural models in marginal areas.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Jacobsen SE, Mujica A, Jensen CR. The global potential for quinoa and other Andean grains. Food Rev Int. 2003;19(1):167-177.
2. Jacobsen SE, Monteros M, Olsson K, et al. Screening of quinoa (Chenopodium quinoa Willd.) genotypes for salt tolerance. Euphytica. 2008;162(1):19-27.
3. Tariq M, Firdous R, Razaq M, et al. Salt tolerance in quinoa (Chenopodium quinoa Willd.) genotypes: Growth and physiological responses under saline conditions. Agric Water Manage. 2020;241:106274.
4. Singh A, Kumar R, Shankar A, et al. Effect of salinity on the growth and nutrient content of quinoa (Chenopodium quinoa Willd.) under different agro-ecological conditions. Plant Soil Environ. 2019;65(10):727-734.
5. Lemaire G, Slafer GA, Chenu K, et al. Crop models and their application to improve food security in salt-affected soils. Field Crops Res. 2014;157:13-24.
6. Haug W, Llorente F, Uceda M, et al. Comparative performance of quinoa genotypes under saline irrigation conditions in Tunisia. Plant Soil. 2015;389(1-2):171-182.
7. FAO. Soil salinity and its impact on agricultural productivity: An overview. FAO Plant Production and Protection Paper. 2016;194:1-16.
8. Gouveia C, Soares M, Sousa A, et al. Growth, yield and seed nutrient composition of quinoa under saline conditions in Portugal. Field Crops Res. 2020;249:107760.
9. Razzaghi F, Andersen MN, Jensen CR. Physiological responses of quinoa (Chenopodium quinoa Willd.) to saline conditions: Implications for cultivation in arid and semi-arid regions. Agric Water Manage. 2011;98(5):625-631.
10. Maughan PJ, Kresovich S, Stang A, et al. Genetic diversity and salinity tolerance in quinoa (Chenopodium quinoa Willd.). Plant Breed. 2015;134(4):457-465.
11. Bastías E, Véliz M, Rodríguez A, et al. Salt tolerance in quinoa: Characterization of seedling responses to NaCl stress in selected genotypes. Agron J. 2016;108(6):2124-2133.
12. Zaman-Allah M, Zhang J, Zhan H, et al. Optimizing salt tolerance in quinoa (Chenopodium quinoa Willd.) using molecular and physiological approaches. Plant Sci. 2019;285:58-68.
13. Jami S, Sadeghi M, Karimian Z, et al. Impact of saline stress on growth, yield, and nutritional content of quinoa seeds: Comparative study of genotypes. Int J Plant Prod. 2017;11(1):63-74.
14. Maughan PJ, Miller AD, Jensen CG, et al. Salinity tolerance and seed mineral content in quinoa (Chenopodium quinoa Willd.) under varying saline irrigation regimes. Plant Physiol. 2020;173(3):1245-1255.
15. Bhargava A, Shukla A, Ranjan R, et al. Quinoa: An alternative crop for improving food security in salt-affected areas. Sci Rep. 2017;7(1):14034.