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Tolerance Indices of Some Quinoa (Chenopodium Quinoa Wild) Genotypes under Different Salinity Levels

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ABSTRACT

The experiment was conducted to determine differential responses of four quinoa genotypes irrigated with water at different salinity levels (800, 4000, and 8000 ppm) during the growing season (2019). The effect of the three salinity levels on quinoa growth was investigated depend on some characters including plant height, chlorophyll content, days of flowering, the weight of grains/plant, and the weight of 1000 seeds of four tested genotypes (Chenopodium quinoa Willd). According to salinity resistance indices, the Chipaya variety was the most tolerant to salinity stress while the Ollague variety was the most sensitive. The results stated that all characters were affected, especially under high salinity level conditions. In general, the most of tested traits displayed recorded obvious variations between the four genotypes and salinity levels on quinoa plants. The correlation and tolerance indices analysis of data has been calculated based on yield grain and its components. The results confirm that the tested varieties can be divided into three groups according to their performance under environmental stress compared to normal conditions.

Key words: *Quinoa, Salt stress, Genotypes, Tolerance, Yield, Correlation*

INTRODUCTION

Plant production and soil salinity are inextricably linked where salinity has always been an important factor for limiting crop production in much of the world [1, 2]. With increasing competition for finite food resources worldwide, the invitation appeared to evaluate and improve cultivated varieties depending on genetic drift and selection in different environmental conditions to ensure future food security [3, 4].

Quinoa (*Chenopodium quinoa* Willd), a food plant belonging to the family Chenopodiaceae [5], has edible parts that include leaves and grains, with the latter reported as the most economically and scientifically investigated [6-8]. It is native to the Andean regions of Chile, Peru, Ecuador, and Bolivia and has been used as a source providing useful food to low-income farmers in these regions thousands of years ago [9]. During the last decades, scientists have become increasingly interested in studying quinoa due to the high nutrition content of its seeds [10, 11], including its high concentration in protein. Additionally, quinoa seeds are rich in unsaturated fatty acids, minerals, and antioxidants [12] and have been reported to be beneficial to patients with celiac disease to their poor gluten content [13]. Quinoa seeds are regarded as good functional food ingredients due to their capacity to decrease the risk of various diseases; thus, the demand for quinoa products increased, leading to an increase in the prices of these products during the last decade [14]. The food and agriculture organization (FAO) has been chosen as one of the plants prepared to provide food safety [15]. Recently, Cao *et al.* (2020) reported that dietary supplementation with quinoa polysaccharide was associated with an improvement in hyperlipidemia caused by the consumption of a high-fat diet [16]. Furthermore, Pereira *et al.* (2020) demonstrated that quinoa varieties represent a good source of bioactive compounds with antibacterial and antifungal activities [17].

The adaption of certain quinoa varieties is possible even under marginal environments where it is notified to be tolerant to many environmental stress conditions including salinity [15, 18-20].

Quinoa belongs to a halophyte with over 3000 accessions presenting a large scale of the diversity of salinity tolerance and other traits. It has been shown that varieties from the Bolivian Altiplano are more tolerant to salinity than varieties from the other areas [21]. However, the determination of parameters that plant breeders might carry out in the field to get better quinoa varieties, for their tolerance to salinity stress, is yet an issue of search [22, 23].

There is a shortage of references related to quinoa growth under salinity stress in our Arab countries. Therefore, we aim to extend a review of crop performances and adaptability based on the studying of genetic variation of four quinoa genotypes through different salinity levels.

MATERIALS AND METHODS

Experiment conditions and experimental design

This study was held using four economical quinoa varieties (Ollague, CO 407, Chipaya, and CICA-17) which have been tested under three salinity irrigation levels (800, 4000, and 8000 ppm) were applied after 20 days from cultivation during season 2019. The experiment was designed in a split-plot design where the salinity levels were placed in the main plot while the tested varieties were placed in a sub plot in three replicates. The sample of soil in the pots was sandy loam with pH 7.8 where the pot height is 60 cm and its diagonal 40 cm.

Plant measurements

Characteristics of quinoa plants were evaluated as follow:

1. Height of plants (cm) at harvest.
2. Leaf area was measured using leaf area device (cm^2) as the mean of three leaves (Leaf number 4, 5, and 6 from top of the plant).
3. Chlorophyll content (SPAD units) was determined using chlorophyll Meter SPAD-502.
4. The number of days of 50 % flowering in plants.
5. Weight of grains/plant (g) using a sensitive digital balance at harvesting.
6. Weight of 1000 seeds (g) using a sensitive digital balance after harvesting.

Tolerance parameter of tested genotypes

Different tolerance parameters to salinity were determined for grain yield/plant of tested genotypes under normal (Yn) and salinity stress conditions (Ys) as indicated in **Table 1**.

Table 1. Salinity stress tolerance indices, equation, and reference

No.	parameter	Equation	Reference
1	Stress susceptibility index (SSI)	$SSI = 1 - (Ys \div Yn) \div SI$, where $SI = 1 - (\hat{Y}s \div \hat{Y}n)$ where $\hat{Y}s$ and $\hat{Y}n$ represent the average of all tested genotypes under high salinity and normal conditions, respectively.	[24]
2	Tolerance index (TOL)	$TOL = Yn - Ys$	[25]
3	Mean productivity (MP)	$MP = (Yn + Ys) \div 2$	[25]
4	Harmonic mean (HM)	$HM = 2(Yn \times Ys) \div (Yn + Ys)$	[26]
5	Geometric mean productivity (GMP)	$GMP = (Yn \times Ys)^{½}$	[27, 28]
6	Stress tolerance index (STI)	$STI = (Yn \times Ys) \div (\hat{Y}\ n)^2$	[27, 26]
7	Superiority measure (SM)	$SM = Ys \div Yn$	[28]
8	Relative performance (RP)	$RP = (Ys \div Yn) \div R$ where $R = (\acute{Y}s \div \acute{Y}n)$.	[29]
9	Yield injury (YI)	$YI = (Yn-Ys) \div Yn * 100$	[30]

RESULTS AND DISCUSSION

Analysis of variance

The results in **Table 2** indicate that there are significant differences between the studied characteristics in general. The data also indicates the presence of clear differences between salinity levels, especially the high level and both other levels **(Figure 1a)**. Also, the results also show that all studied traits decrease their values by increasing the level of salinity except for the characteristic of the number of days required for flowering that go in the opposite direction as they decrease by increasing the influence of the salinity level **(Table 2)**.

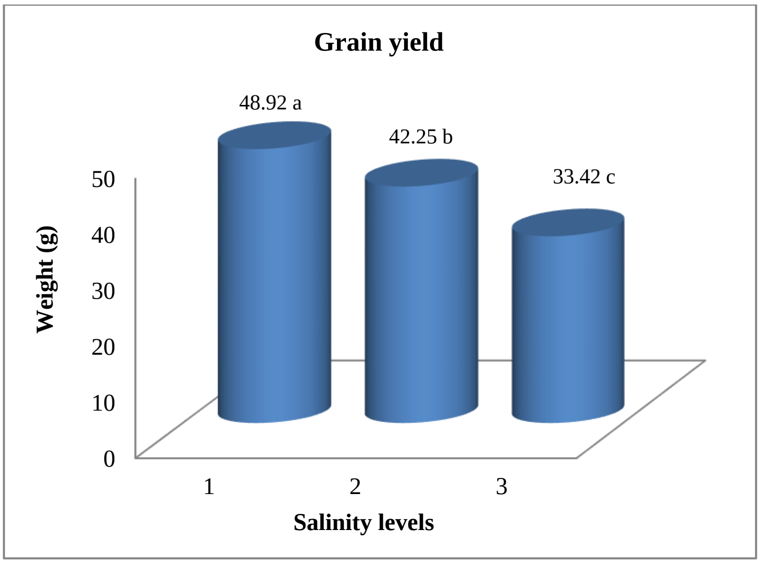
On the other hand, **Figure 1b** shows the differences between the tested genotypes through grain yields/plant a cross salinity levels but the figure shows that there is no significant difference between varieties 4 and 3, but they outperform the cultivar 1.

The correlation coefficient among tested characters

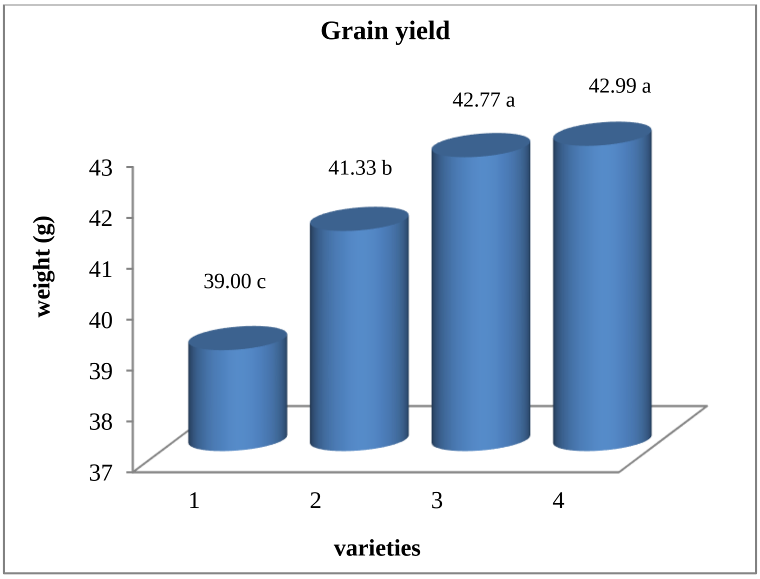
The results in **Table 3** indicate that the correlation coefficients between the characteristics studied across the trial conditions were strong and positive and ranged from 0. 727 to 0.964 where the lowest value was recorded between leaf area and Chlorophyll content while the highest value was recorded between days of flowering and weight of grains/plant.

Table 2. Mean performance of tested genotypes for tested traits under three salinity levels.

Salinity level	Genotype	Plant height (cm)	Leaf area (cm^2)	Chlorophyll content (SPAD)	Days of 50% flowering	Weight of grains /plant (g)	Weight of 1000 seeds (g)
Low	Ollague	107.67	18.00	53.33	81.67	48.33	3.167
	CO 407	96.00	18.60	50.33	78.33	47.00	3.367
	Chipaya	103.00	19.33	51.00	80.67	49.00	3.200
	CICA-17	109.67	21.53	48.33	82.67	51.33	3.400
Middle	Ollague	82.33	15.50	45.57	77.00	40.67	2.933
	CO 407	81.33	16.87	44.67	77.00	42.67	3.000
	Chipaya	95.00	18.23	46.87	75.00	42.33	3.133
	CICA-17	95.00	17.50	42.00	76.33	43.33	3.000
High	Ollague	57.33	10.83	34.67	66.67	28.00	2.533
	CO 407	61.67	15.00	36.33	71.67	34.33	2.933
	Chipaya	81.67	16.00	37.50	70.67	37.00	3.033
	CICA-17	73.33	16.67	35.67	67.67	34.33	2.617
$LSD_{(0.05)}$		1.145	0.14	1.56	0.82	2.16	0.02



a)



b)

Figure 1. a) Comparison between varieties across salinity levels. Salinity level 1, 2, and 3 are 800, 4000, and 8000 respectively. b) Comparison between salinity levels of all tested varieties. Varieties 1, 2, 3, and 4 are Ollague, CO 407, Chipaya, and CICA-17 respectively.

Table 3. Correlation between tested characters and grain yield.

Correlation coefficient	Plant height	Leaf area	Chlorophyll content	Days of flowering	Weight of 1000 seeds
Leaf area	0.888				
Chlorophyll content	0.879	0.727			
Days of flowering	0.885	0.796	0.927		
Weight of 1000 grains	0.839	0.846	0.812	0.861	
Weight of grains/plant	0.955	0.908	0.918	0.964	0.901

Tolerance parameters

The results presented in **Table 4** showing a clear difference between the results of the grain yield/plant under the high salinity level (Ys) compared to normal conditions (Yn) through the tolerance indices of the tested cultivars. Through the stress susceptibility index (SSI) parameter, one or two tolerant cultivars to salinity can be determined. When the value of SSI is less, this meant that the tolerance of cultivar to salinity stress will be higher. **Table 3** shows the SSI values for grain yield which was in the range from 0.773 in Chipaya cultivar as a tolerant to 1.327 in Ollague as a sensitive cultivar. While CICA-17 cultivar can be considered as moderate salinity tolerance (1.045).

Estimation of tolerance indices stated that the highest stress tolerance (TOL) value as stress susceptibility index (SSI) value was related to Ollague cultivar indicating this cultivar had higher grain yield reduction under high salinity level compared with normal conditions and the highest salinity sensitivity **(Table 3)**.

Chipaya and CICA-17 were the tolerant cultivars according to mean productivity (MP), harmonic mean (HM), geometric mean productivity (GMP), and stress tolerance index (STI) were recorded the highest values which greater than the general mean of all cultivars (41.17, 39.61, 40.38 and 0.684 respectively).

Based on the superiority measure (SM) and relative performance (RP), the cultivars Chipaya and CO 407 had the highest values which exceeded the mean of all tested cultivars while the Ollague cultivar recorded the lowest value. According to the yield injury (YI) parameter, the Ollague cultivar is ranked the first in the damage and consequently, the crop is decreased by exposure to high salinity while the least affected (least harmful) cultivar was the Chipaya variety **(Table 4)**.

Table 4. Tolerance parameters of quinoa cultivars under high salinity level (Y**s**) and normal (Y **n)** conditions based on grain yield/plant.

Cultivar	Y(n)	Y(s)	SSI	TOL	MP	HM	GMP	STI	SM	RP	YI
Ollague	48.33	28.00	1.327	20.33	38.17	35.46	36.79	0.566	0.579	0.848	42.06
CO 407	47.00	34.33	0.851	12.67	40.67	39.68	40.17	0.674	0.730	1.069	26.96
Chipaya	49.00	37.00	0.773	12.00	43.00	42.16	42.58	0.758	0.755	1.105	24.49
CICA-17	51.33	34.33	1.045	17.00	42.83	41.14	41.98	0.736	0.669	0.979	33.12
Mean	48.92	33.42	0.999	15.50	41.17	39.61	40.38	0.684	0.683	1.000	31.66

Yn = mean grain yield/plant of studied cultivar under non-stress condition, Ys = mean grain yield/plant tested variety under high salinity stress, SSI = stress susceptibility index, TOL = tolerance index, MP = mean productivity, HM = Harmonic mean, GMP = geometric mean productivity, STI = stress tolerance index, SM= Superiority measure, RP= Relative performance and Yi= Yield injury

The presence of significant differences between studied characteristics under various environmental conditions, as well as between a group of genotypes indicates the importance of distributing these genotypes according to their compatibility with these different conditions.

The Correlation between two characters can be affected by inheritance, environmental condition, or the interaction between them. The characteristics selected for the study were considered as they all recorded a high correlation with the yield of grains **(Table 4)**, especially the number of days until flowering, which confirms that it is strongly related to the grain yield, which they nominate as an important quality of selection for them under salinity conditions. In the same manner, Cruz *et al.* (2019) and Carvalho *et al.* (2018) stated that the simple correlation between two characters is usually determined using the Pearson's linear correlation coefficient, which depends on the ratio of the two-variable joint difference known as covariance and the output of their respective standard deviations [31, 32].

Therefore, attention to focus on the parameters of stress tolerance is a requirement to determine the possibility of sharing each genotype in an environment. Salinity tolerant variety can satisfy is determined as genotype which achieves considerably greater productivity than average under salinity stress. The data in **Table 3** can distribute the studied quinoa cultivars based on grain yield under both non-stress and salinity stress and these results are harmonic with Majidi *et al.* (2011), and Badran and Moustafa (2014) and Badran (2015) who stated that STI, HM (harmonic mean) and MP (geometric mean productivity) can be effective indices for pick out high productivity varieties under both non-stress and salinity stress [3, 33, 34]. According to the results in **Table 4** can be useful to divide the tested cultivars into three groups based on their grain yield as follow: the first group, good express cultivar behavior in both normal and salinity stress (*i.e.* Chipaya cultivar), the second group: cultivars with good behavior under non-stress only (*i.e.* Ollague cultivar), the third group: genotype medium in performance in both normal conditions and salinity stress (*i.e.* CO 407 and CICA-17 cultivars). These results are similar to Fernández (1992) who reported that the cultivars were classified into four groups according to their behavior under normal conditions and stress conditions [27].

CONCLUSION

The study focused on evaluating a group of genotypes of quinoa under different levels of salinity. The study was based on the calculation of a set of tolerance parameters for saline stress, and accordingly, the four genotypes tested were classified into three groups. The Chipaya variety expresses itself well under salinity stress and normal conditions. Ollague variety expresses itself well under normal conditions only (non-stress). The third group includes CICA-17 and CO 407 and they occupy a middle case under the conditions of the experiment.

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ETHICS STATEMENT : None

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