

## RESPONSE OF QUINOA (*Chenopodium quinoa* Willd.) GENOTYPES UNDER CONTROLLED CONDITIONS OF SALT STRESS

Camilo Alexander MESTANZA UQUILLAS<sup>1</sup>, Nelly Yuliana ZAMBRANO NORIEGA<sup>2</sup>,  
Diana Verónica VÉLIZ ZAMORA<sup>1</sup>, John Jairo PINARGOTE ALAVA<sup>3</sup>, Enrique OLMOS<sup>4</sup>,  
Nieves FERNÁNDEZ-GARCÍA<sup>4</sup>

<sup>1</sup>Universidad Técnica Estatal de Quevedo (UTEQ), Quito Avenue, Km 1.5,  
road to Santo Domingo de los Tsáchilas, Quevedo, Los Ríos, Ecuador, EC120501

<sup>2</sup>Graduate of the Universidad Técnica Estatal de Quevedo (UTEQ), Quito Avenue, Km 1.5,  
road to Santo Domingo de los Tsáchilas, Quevedo, Los Ríos, Ecuador, EC120501

<sup>3</sup>Universidad Estatal Península de Santa Elena (UPSE), Main Avenue La Libertad - Santa Elena,  
La Libertad, Santa Elena, Ecuador, CP:240350

<sup>4</sup>Departamento de Biología del Estrés y Patología Vegetal, CEBAS-CSIC,  
Campus Universitario de Espinardo Edificio 25, Murcia, España

Corresponding author email: cmestanza@uteq.edu.ec

### Abstract

The purpose of this research was to study the effect of salinity on emergence, relative water content in leaves, root development and biomass of quinoa genotypes. For this purpose, a completely randomized design (CRD) with factorial arrangement was applied, consisting of two factors: A. genotypes, with 30 quinoa varieties and B. salinity dose, with two levels of sodium chloride (0 mM and 300 mM), with three replications. The application of NaCl in the daily irrigation water did not affect plant emergence, registering the highest overall average (83%) compared to the control group (64%). However, it negatively and significantly affected quinoa plant growth and relative water content percentages as NaCl accumulated in the soil, increasing the concentration of salts in the soil. The root system was also affected, causing an elongation of the main root, but considerably reduced its volume, generating a lower biomass production. Finally, it was concluded that the quinoa genotypes labelled O-1, O-2, O-3, O-5, O-10, X3, X4, and X5 exhibited the least sensitivity to salt stress, showing the best resistance among all tested varieties.

**Key words:** biomass, electrical conductivity, emergence, quinoa, yields.

### INTRODUCTION

One of the major abiotic factors limiting agricultural production on a global scale is soil salinity (Raza et al., 2022). This condition shows a tendency to increase in the coming years, both globally (Hopmans et al., 2021) and in Ecuador, where over time large agricultural areas have been degraded (Medina et al., 2022), turning them into arid zones, which together with the extreme temperatures recorded in recent years, have led to the accumulation of salts in the upper layers of the soil, thus representing a threat to agricultural production, and therefore to the economy of thousands of farmers (Argüello et al., 2019).

In this context, the intensification of conventional agricultural techniques has led to an increase in the rate of salinization (Alkharabsheh et al., 2021), which, in addition

to leading to a decrease in the productive parameters of the crop, has caused radical scenarios such as land abandonment by producers (Lasanta et al., 2019), largely due to their lack of knowledge when selecting salt stress tolerant crops (Hernández, 2019), such as quinoa (*Chenopodium quinoa* Willd.).

However, it should be noted that, despite the fact that quinoa in Ecuador has historically been considered a secondary crop, and that the cultivated areas and per capita consumption do not exceed the records achieved by Andean countries such as Peru and Bolivia (Hinojosa et al., 2021) is a crop with great projection for the future, so it is necessary to take advantage of its great capacity to adapt to extreme climatic conditions (Shi & Gu, 2020) present in ecotypes such as the Altiplano, inter-Andean valleys, salt flats, yungas, and coastal areas (Jaikishun et al.,

2019), as well as its enormous nutritional benefits (Khaitov et al., 2021).

In view of the above, this study sought to analyze the agronomic response of quinoa genotypes to salt stress induction. The purpose of this study was to identify and select biologic materials with capacity for development and productivity under adverse conditions, as a measure to mitigate the low yields achieved in regions of the world that are highly affected by this factor.

## **MATERIALS AND METHODS**

### **Location**

The research was carried out at the University Campus "La María" of the State Technical University of Quevedo, located of the road Quevedo - El Empalme, canton Mocache, province of Los Ríos - Ecuador, between the geographical coordinates of 1°6'28" South latitude and 70°27'13" West longitude, at an altitude of 72 meters above sea level. Under the following agro-meteorological characteristics: average temperature 26°C, relative humidity 87.71%, heliophany 915.56 daylight hours/year, annual precipitation 2274.29 mm, and a tropical humid forest ecological zone (bh-T).

### **Experiment management**

Peat was used for this study. The pots were filled using two kilograms of peat per pot, then 12 grams of 10-30-10 fertilizer was added to each pot to promote plant growth, and then each pot was moistened to field capacity. Planting was carried out in 4-liter pots on metal tables. Each pot corresponded to a different genotype, so a label was placed with the respective name of each treatment. For sowing, three seeds were placed at a depth of less than 0.5 cm per hole (five) positioned differently, covered by a thin layer of the substrate used, and finally moistened according to the treatments (water/NaCl). Once fifteen days had elapsed since sowing, the cultural work of re-planting was carried out to avoid overpopulation of quinoa seedlings per hole, leaving two plants per position.

The application of the NaCl solution was used in a concentration of 300 mM (millimoles per liter) to the thirty treatments destined for the study while the other half was kept as a control, irrigated with good quality water; it should be noted that the solution was prepared using

351 g of NaCl in 20 L of quality water, which was mixed and subjected to low heat until it was completely dissolved and transformed into a homogeneous mixture. This process was carried out weekly. For this study, 4 kg of NaCl and 12 bottles of water of 20 L were used for the treatments with dose 2 (300 mM) and 12 bottles of water of 20 L for the treatments with dose 1 (0 mM). Irrigation of the treatments with both doses was carried out at a daily frequency of once a day during the first 30 days sowing, in the following days, irrigation was carried out with the same frequency, but twice a day, in the early morning and late afternoon, due to the evapotranspiration of the plants produced by the high ambient temperatures during that period of time. Irrigations were carried out for 8 weeks.

To determine the electrical conductivity of the different soil samples (three with NaCl and three with water), the first step was to wash the six plastic containers with soap or detergent, after which they were labeled. Next, 20 grams of soil from all the samples were weighed on the analytical balance and placed in each container, and 50 ml of distilled water was added to each one, then each sample was shaken with a glass rod for 5 minutes and left to stand for 15 minutes, and this shaking and resting step was repeated. Finally, the samples were left to stand for 24 hours. Once the 24 hours of rest had elapsed, the conductivity meter (Hach Model HQ440d multiparametric) was introduced in each sample. The electrical conductivity was read once the reading was stabilized (Soriano, 2018). This procedure was performed 35 and 60 days after sowing.

### **Research design and statistical analysis**

A completely randomized design was applied in a factorial arrangement (A x B), consisting of two factors: genotypes (A) and salinity dose (B). Thirty quinoa genotypes (G1-G30) were evaluated, with two doses of sodium chloride (D1: 0 mM NaCl and D2: 300 mM NaCl), with three replications, giving a total of 180 experimental units (Table 1). The interpretation of the results was performed by analysis of variance (ANOVA) and the means were compared through Tukey's test ( $P \leq 0.05$ ).

### **Emergence rate**

The number of plants emerged 8 days after sowing was counted. The following formula was used (Rodríguez et al., 2014):

$$E \% = \frac{\text{number of plants emerged}}{\text{total number of seeds sown}} \times 100$$

Table 1. Description of treatments

| Treatments | Detail (Genotype)               | Origin    |
|------------|---------------------------------|-----------|
| 1          | G. 26 + 0 mM NaCl               | Chile     |
| 2          | G. 36 + 0 mM NaCl               | Chile     |
| 3          | G. 41 + 0 mM NaCl               | Chile     |
| 4          | G. 42 + 0 mM NaCl               | Chile     |
| 5          | G. 48 + 0 mM NaCl               | Chile     |
| 6          | G. 49 + 0 mM NaCl               | Chile     |
| 7          | G. 52 + 0 mM NaCl               | Chile     |
| 8          | G. 54 + 0 mM NaCl               | Chile     |
| 9          | G. O-1 + 0 mM NaCl              | Chile     |
| 10         | G. O-2 + 0 mM NaCl              | Chile     |
| 11         | G. O-3 + 0 mM NaCl              | Chile     |
| 12         | G. O-4 + 0 mM NaCl              | Chile     |
| 13         | G. O-5 + 0 mM NaCl              | Chile     |
| 14         | G. O-6 + 0 mM NaCl              | Chile     |
| 15         | G. O-7 + 0 mM NaCl              | Chile     |
| 16         | G. O-8 + 0 mM NaCl              | Chile     |
| 17         | G. O-9 + 0 mM NaCl              | Chile     |
| 18         | G. O-10 + 0 mM NaCl             | Chile     |
| 19         | G. J4 + 0 mM NaCl               | Argentina |
| 20         | G. Faro + 0 mM NaCl             | Chile     |
| 21         | G. Regalona + 0 mM NaCl         | Chile     |
| 22         | G. Pata de venado + 0 mM NaCl   | Ecuador   |
| 23         | G. dulce + 0 mM NaCl            | Ecuador   |
| 24         | G. O-10 M + 0 mM NaCl           | Chile     |
| 25         | G. J4-O10 + 0 mM NaCl           | Argentina |
| 26         | G. Tunkahuan + 0 mM NaCl        | Ecuador   |
| 27         | G. X2 + 0 mM NaCl               | Chile     |
| 28         | G. X3 + 0 mM NaCl               | Chile     |
| 29         | G. X4 + 0 mM NaCl               | Chile     |
| 30         | G. X5 + 0 mM NaCl               | Chile     |
| 31         | G. 26 + 300 mM NaCl             | Chile     |
| 32         | G. 36 + 300 mM NaCl             | Chile     |
| 33         | G. 41 + 300 mM NaCl             | Chile     |
| 34         | G. 42 + 300 mM NaCl             | Chile     |
| 35         | G. 48 + 300 mM NaCl             | Chile     |
| 36         | G. 49 + 300 mM NaCl             | Chile     |
| 37         | G. 52 + 300 mM NaCl             | Chile     |
| 38         | G. 54 + 300 mM NaCl             | Chile     |
| 39         | G. O-1 + 300 mM NaCl            | Chile     |
| 40         | G. O-2 + 300 mM NaCl            | Chile     |
| 41         | G. O-3 + 300 mM NaCl            | Chile     |
| 42         | G. O-4 + 300 mM NaCl            | Chile     |
| 43         | G. O-5 + 300 mM NaCl            | Chile     |
| 44         | G. O-6 + 300 mM NaCl            | Chile     |
| 45         | G. O-7 + 300 mM NaCl            | Chile     |
| 46         | G. O-8 + 300 mM NaCl            | Chile     |
| 47         | G. O-9 + 300 mM NaCl            | Chile     |
| 48         | G. O-10 + 300 mM NaCl           | Chile     |
| 49         | G. J4 + 300 mM NaCl             | Argentina |
| 50         | G. Faro + 300 mM NaCl           | Chile     |
| 51         | G. Regalona + 300 mM NaCl       | Chile     |
| 52         | G. Pata de venado + 300 mM NaCl | Ecuador   |
| 53         | G. Dulce + 300 mM NaCl          | Ecuador   |
| 54         | G. O-10 M + 300 mM NaCl         | Chile     |
| 55         | G. J4-O10 + 300 mM NaCl         | Argentina |
| 56         | G. Tunkahuan + 300 mM NaCl      | Ecuador   |
| 57         | G. X2 + 300 mM NaCl             | Chile     |
| 58         | G. X3 + 300 mM NaCl             | Chile     |
| 59         | G. X4 + 300 mM NaCl             | Chile     |
| 60         | G. X5 + 300 mM NaCl             | Chile     |

### Relative leaf water content (RLWC)

A fully expanded whole leaf was randomly selected from the top of the plants. The selected leaves were detached from the plants, dried with

a cloth, and the tops and bottoms of all leaves were cut off, leaving a 5-cm intermediate section. They were immediately placed in the weighted tubes and covered so that there was no loss or gain of moisture from the system. They were quickly placed in a cooler at 15°C. All samples were taken to the laboratory as soon as possible, where all tubes with the samples were immediately weighed, which was considered as fresh weight (FW) (minus the weight of the empty tube), then 1 cm of distilled water was added to each tube and the samples were placed in a refrigerator at 4°C for 24 hours to allow the leaves to reach full turgor. The leaf samples were then removed from the tube and carefully dried with a paper towel and weighed (TW: Turgent weight). Then, the sampled leaves were placed in labelled paper bags to be dried in an oven at 70°C for 24 hours, and finally the leaves were reweighed (DW: Dry weight).

Treatments were evaluated at two different vegetative stage at 25 and 55 days after sowing. The following formula was used to determine relative leaf water content (Pask et al., 2012):

$$RLWC (\%) = \frac{FW - DW}{TW - DW} \times 100$$

### Plant height

Plant height was measured in centimetres from the base of the stem to the top of the plant, using a tape measure. They were evaluated at two different vegetative stage at 35 and 60 days after sowing.

### Stem diameter

It was measured in centimetres, using a calliper at the base of the stem. They were evaluated at two different vegetative stage at 35 and 60 days after sowing.

### Root length

The whole plant was carefully removed from its container. The roots were rinsed with abundant water to remove soil particles and then dried with absorbent towels. Subsequently, the main (tap) root was measured in centimetres from the root collar to the root apex. They were evaluated at two different vegetative stage at 35 and 60 days after sowing.

### Root system volume

It was determined by means of a free software (Safira), for this, the root system was placed on a white background and a scale (5 cm or 10 cm) was drawn on its lower part. A high-quality photo was taken and scanned in this program,

where the roots were analyzed, specifying the space occupied by the root in the soil. Roots were evaluated at two different vegetative ages at 35 and 60 days after sowing.

#### Aerial biomass, root and total fresh weight

The whole plant was extracted, separating the plant structures (aerial and root), and the samples were weighed with the aid of an analytical balance. Finally, all the weights recorded for the different plant organs were added together to determine the fresh biomass reached by each genotype 35 and 60 days after sowing.

#### Aerial biomass, root and total dry weight

The fresh samples were collected, depositing the plant structures (aerial and root) in paper bags that were taken to the laboratory. The samples were placed in an oven at 65°C for 48 hours. They were then weighed on an analytical balance to obtain the dry weight in grams. Finally, all the weights recorded for the different plant organs were added together to determine the dry biomass attained by each genotype 35 and 60 days after sowing.

## RESULTS AND DISCUSSIONS

#### Soil electrical conductivity analysis

Table 2 shows the electrical conductivity analysis of the soil, showing how the NaCl concentration increased with the daily irrigation of the saline solution during the study, demonstrating that at 35 days the substrates to which a dose of 300 mM NaCl was applied obtained 7.5 dS/m, a value that represents a moderately saline soil, in contrast to the group of substrates with a dose of 0 mM NaCl, which showed a value of 1.77 dS/m, indicating a low degree of salinity.

Table 2. Electrical conductivity of the soil

| Electrical conductivity of the soil (E.C) |              |                    |             |                    |
|-------------------------------------------|--------------|--------------------|-------------|--------------------|
| Dose of NaCl                              | 35 das       |                    | 60 das      |                    |
|                                           | E.C.* (dS/m) | Degree of salinity | E.C. (dS/m) | Degree of salinity |
| 0 mM                                      | 1.77         | Bajo               | 2.30        | Leve               |
| 300 mM                                    | 7.5          | Medio              | 11.32       | Muy alto           |

\*E.C.: Electrical conductivity; das: Days after sowing

At 60 days, the substrates used for the evaluation of the controls (0 mM NaCl) showed a value of 2.30 dS/m, indicating a slight degree of salinity.

#### Emergence rate

According to the ANOVA obtained for the two doses of NaCl on the emergence rate at 8 days,

highly significant differences were found, since the genotypes under the application of NaCl with a dose of 300 mM obtained the highest results with an average of 83%, compared to the control dose (0 mM NaCl) which obtained the lowest value with 64% (Table 3).

Table 3. Effect of NaCl doses on emergence rate at 8 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Dose of NaCl | Emergence fee (%) |
|--------------|-------------------|
| 0 mM         | 64%               |
| 300 mM       | 83%               |

The genotypes that stood out with dose 2 (300 mM NaCl) were: 36, 42, 48, 49, O-7 and X3 with an average of 100%, while the genotypes with dose 1 (0 mM NaCl) recorded the lowest values despite being the same genotypes, genotype 36 and 42 obtained an average of 86.67%, genotype 48 with 80%, 49 with 73.33%, O-7 with 40% and X3 with 80%.

#### Relative water content in leaves

Table 4 shows the analysis obtained for the two doses of NaCl with respect to the relative water content in the leaves after 25 days. On this occasion, the genotypes with a dose of 0 mM NaCl obtained the highest results with an average of 73%, presenting highly significant differences in relation to the dose of 300 mM, which obtained the lowest result with 57%.

Table 4. Effect of NaCl doses on relative leaf water content (RLWC) 25 days after sowing in quinoa genotypes evaluated at the University Campus "La María"

| Dose of NaCl | RLWC (%) |
|--------------|----------|
| 0 mM         | 73%      |
| 300 mM       | 57%      |

The genotype with dose 1 (0 mM NaCl) that stood out with the highest average was O-5 with a mean of 85.83%. However, the genotypes with an application dose of 300 mM NaCl maintained a similar trend with values within a range of 60-80%.

On the other hand, it was observed that genotype O-10 with a dose of 300 mM NaCl obtained an average of 82%, which does not differ from dose 1 of 0 mM NaCl whose average was 82.22%. In the same way, genotype X5 with dose 2 (300 mM NaCl) reached an average of 74.49%, being similar to dose 1 (0 mM NaCl) with an average

of 75.16% and, finally, genotype O-6 with dose 2 registered a value of 65.64% similar to dose 1 with 65.76%.

At 55 days, by means of ANOVA, it was possible to observe a significant decrease in the RLWC in the genotypes with dose 2 (300 mM NaCl) up to 30%, presenting an average of 40% compared to the genotypes of the control group that reached the highest values with an average of 84% (Table 5).

Table 5. Effect of NaCl doses on relative leaf water content (RLWC) 55 days after sowing in quinoa genotypes evaluated at the University Campus "La María"

| Dose of NaCl | RLWC (%) |
|--------------|----------|
| 0 mM         | 84%      |
| 300 Mm       | 40%      |

The genotype with dose 1 (0 mM NaCl) obtained the highest record with a mean of 98.07% was O-5. It should be noted that the genotypes with the addition of 300 mM NaCl that stood out with the highest percentages were recorded genotypes X4 with a mean of 70.29%, followed by genotype O-10 with 64.69%, genotype X3 with 62.34%, genotype O-1 with 60.05%, genotype X5 with 57.30%, genotype O-2 with 55.83%, O-5 with 53.98%, and finally genotype O-3 with 53.71%; which reached the highest percentages in RLWC.

### Plant height

The data analyzed for the interaction of the factors on plant height at 35 days show highly significant differences, with the genotypes of the control group with dose 1 (0 mM NaCl) reaching the greatest plant height with an average of 18 cm, compared to the genotypes of dose 2 (300 mM NaCl) that recorded the lowest value with an average of 10 cm (Table 6).

Table 6. Effect of NaCl doses on plant height at 35 days after sowing, in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Plant height (cm) |
|--------------|-------------------|
| 0 mM         | 18 cm             |
| 300 mM       | 10 cm             |

The genotype that stood out with dose 1 (0 mM NaCl) was J4O-10 with a height of 26.17 cm, while the genotype that obtained the greatest height for dose 2 (300 mM NaCl) was X4 with 20.67 cm.

Likewise, the analysis for the 60 days shows that the genotypes of the control group reached the highest results with an average height of 47 cm, unlike the genotypes with dose 2 (300 mM NaCl) that reached an average height of 7 cm (Table 7).

Similarly, genotype J4O-10 with dose 1 (0 mM NaCl) showed the greatest height with a record of 76.33 cm, while of the 30 genotypes with dose 2 (300 mM NaCl), X4 stood out with a height of 31.17 cm.

Table 7. Effect of NaCl doses on plant height at 60 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Dose of NaCl | Plant height (cm) |
|--------------|-------------------|
| 0 mM         | 47 cm             |
| 300 mM       | 7 cm              |

### Stem diameter

The ANOVA for the variable stem diameter at 35 days showed highly significant differences, with the genotypes of the control group reaching the highest values with a mean of 0.23 cm, compared to the genotypes of dose 2 that obtained the lowest register with 0.12 (Table 8).

Table 8. Effect of the doses of NaCl on stem diameter 35 days after sowing, in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Stem diameter (cm) |
|--------------|--------------------|
| 0 mM         | 0.23 cm            |
| 300 Mm       | 0.12 cm            |

Genotype J4O-10 with dose 1 (0 mM NaCl) reached the largest stem diameter with 0.32 cm, while of the genotypes with dose 2 (300 mM NaCl), X4 stood out with a stem diameter of 0.22 cm.

Likewise, the ANOVA at 60 days showed that the genotypes of the control group reached the highest mean with a stem diameter of 0.38 cm, while the genotypes established in a saline medium reached a mean of 0.05 cm (Table 9).

Table 9. Effect of NaCl doses on stem diameter 60 days after sowing in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Stem diameter (cm) |
|--------------|--------------------|
| 0 mM         | 0.38 cm            |
| 300 mM       | 0.05 cm            |

As for the genotype that achieved the highest stem diameter result with 0.50 cm was J4O-10 with dose 1 (0 mM NaCl), while of the genotypes with dose 2 (300 mM NaCl) X4 again prevailed with a stem diameter of 0.25 cm.

**Root length**

As can be seen in Table 10, in the analysis obtained for the two doses of NaCl in the variable root length at 35 days, there was a highly significant difference. The highest results were recorded for the group of genotypes that were established in a saline medium with an average of 20 cm, in relation to the control group that reached 15 cm.

Table 10. Effect of the doses of NaCl on root length 35 days after sowing, in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Root length (cm) |
|--------------|------------------|
| 0 mM         | 15 cm            |
| 300 mM       | 20 cm            |

Genotype X3 had the longest root length with 37 cm, while the control group, the genotype with the longest length was X2 with 24.5 cm. The analysis carried out for 60 days showed that the highest results were recorded by the control group with an average of 20 cm in relation to the genotypes that were established in a saline medium, which reached 9 cm (Table 11).

Table 11. Effect of NaCl doses on root length 60 days after sowing, in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Root length (cm) |
|--------------|------------------|
| 0 mM         | 20 cm            |
| 300 mM       | 9 cm             |

On the other hand, genotype X3 with dose 2 (300 mM NaCl) prevailed with the greatest root length with 40 cm, while in the control group the genotype that presented the greatest length was X2 with 31 cm.

**Root system volume**

Table 12 shows the analysis obtained for the two doses of NaCl for the variable root system volume at 35 days, showing a highly significant difference. The genotypes with dose 1 (0 mM NaCl) reached the highest average with 10 cm<sup>3</sup> as opposed to the genotypes with dose 2 (300 mM NaCl) which registered the lowest value of 3 cm<sup>3</sup>. The genotype that reached the highest root system volume was X4 with dose 1 (0 mM

NaCl) with 26.19 while genotype X3 stood out with dose 2 (300 mM NaCl) with a volume of 7.78 cm<sup>3</sup>.

Table 12. Effect of the doses of NaCl on the volume of the root system 35 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Dose of NaCl | Root system volume |
|--------------|--------------------|
| 0 mM         | 10 cm <sup>3</sup> |
| 300 mM       | 3 cm <sup>3</sup>  |

In the 60-day analysis, the genotypes with dose 1 (0 mM NaCl) again stood out, reaching the highest average with 31 cm<sup>3</sup> in relation to the genotypes that were under salt stress (Table 13).

Table 13. Effect of NaCl doses on the volume of the root system 60 days after sowing, in quinoa genotypes evaluated at the "La María" University Campus

| Dose of NaCl | Root system volume |
|--------------|--------------------|
| 0 mM         | 31 cm <sup>3</sup> |
| 300 mM       | 2 cm <sup>3</sup>  |

The genotype that reached the highest volume of the root system was again the X4 with dose 1 (0 mM NaCl) with 56.75 cm<sup>3</sup>, observing that the treatments under the saline effect, obtained a lower volume in the roots in relation to the control group. This study showed that root volume is a good predictor of plant performance, those plants with higher root volume had higher survival rates and good organ development, such as genotype X3, which reached an average volume of 14.28 cm<sup>3</sup>, as opposed to those with lower root volume, which did not survive.

**Aerial biomass, root and total fresh weight**

The analysis obtained for the effect of the two doses of NaCl at 35 days showed highly significant differences, demonstrating that the genotypes under the application of NaCl with a dose of 0 mM obtained the highest results in all fresh weights, both aerial and radical and total with averages of 10.40, 1.01 and 11.41 g respectively, compared to the genotypes that were established in a saline medium (Table 14).

Table 14. Effect of NaCl doses on aerial, root and total fresh weight 35 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Fresh Weight (g) |        |         |       |
|------------------|--------|---------|-------|
| Dose of NaCl     | Aerial | Radical | Total |
| 0 mM             | 10.40  | 1.01    | 11.41 |
| 300 mM           | 3.71   | 0.50    | 4.21  |

Genotype O-4 with dose 1 (0 mM NaCl) stood out with the highest values, obtaining 22 g in the aerial part; 2 g in radical and 24 g in total fresh weight. While the genotypes that stood out under salt stress were X5 in terms of aerial fresh weight with 8.33 g, X3 stood out in the radical part with 1.03 g, with genotype X5 obtaining the highest total value with 8.67 g.

In the analysis obtained for the 60 days also showed that the genotypes under the application of NaCl with a dose of 0 mM obtained the highest results in all fresh weights, both aerial and radical and total with averages of 21.58; 2.16 and 23.74 g, respectively, compared to the genotypes that were established in a saline medium that recorded the lowest values (Table 15).

Table 15. Effect of NaCl doses on aerial, radical and total fresh weight at 60 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Fresh Weight (g) |        |         |       |
|------------------|--------|---------|-------|
| Dose of NaCl     | Aerial | Radical | Total |
| 0 mM             | 21.58  | 2.16    | 23.74 |
| 300 mM           | 2.19   | 0.17    | 2.36  |

In terms of aerial fresh weight, the highest results were recorded by genotype O-4 with 32.67 g and O-9 with 32.63 g with dose 1 (0 mM NaCl); genotype X4 also stood out with 4 g and O-4 with 3.67 g with respect to root fresh weight. Therefore, genotype O-4 recorded the highest value in total fresh weight with a mean of 36.34 g. While the genotypes that stood out under salt stress were X5 in terms of aerial fresh weight with 11.33 g; in the radical part, X3 stood out with 1.07 g; being genotype X5 the one that obtained the highest total value with 12.33 g.

#### **Aerial, root and total dry weight**

The analysis obtained for the effect of the two doses of NaCl at 35 days showed highly significant differences, demonstrating that the genotypes under the application of NaCl with a dose of 0 mM obtained the highest results in all dry weights, both aerial and radical and total with averages of 0.80, 0.12 and 0.92 g respectively, compared to the genotypes that were established in a saline medium (Table 16). It was observed that genotypes O-4 and 36 with dose 1 (0 mM NaCl) stood out with 1.29 and 1.27 g, respectively, being the highest values in aerial dry weight. Genotype X4 with dose 1

stood out in root dry weight with 0.57 g. Thus, genotype O-4 with dose 1 (0 mM NaCl) reached the lowest average total dry weight with 1.65g. While the genotypes that stood out under salt stress were X5 in terms of aerial fresh weight with 0.71 g; in the radical part, X3 stood out with 0.13 g, with genotype X5 obtaining the highest total value with 0.73 g.

Table 16. Effect of NaCl doses on aerial, root and total dry weight 35 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Dry Weight (g) |        |         |       |
|----------------|--------|---------|-------|
| Dose of NaCl   | Aerial | Radical | Total |
| 0 mM           | 0.80   | 0.12    | 0.92  |
| 300 mM         | 0.32   | 0.04    | 0.36  |

The analysis obtained for the 60 days showed that the genotypes under the application of NaCl with a dose of 0 mM obtained the highest results in all dry weights, both aerial and radical and total with averages of 2.17, 0.32 and 2.49 g, respectively, compared to the genotypes that were established in a saline medium that registered the lowest values (Table 17).

Table 17. Effect of NaCl doses on aerial, root and total dry weight at 60 days after sowing, in quinoa genotypes evaluated at the University Campus "La María"

| Dry Weight (g) |        |         |       |
|----------------|--------|---------|-------|
| Dose of NaCl   | Aerial | Radical | Total |
| 0 mM           | 2.17   | 0.32    | 2.49  |
| 300 mM         | 0.31   | 0.03    | 0.34  |

The genotypes that achieved the highest results in aerial dry weight were genotype O-4 with 3.93 g and O-9 with 3.75 g with dose 1 (0 mM NaCl); genotype X4 also stood out with dose 1 with 0.65 g with respect to fresh root weight. Therefore, genotype O-4 recorded the highest value in total dry weight with a mean of 4.55 g. While the genotypes that stood out under salt stress were X5 in terms of aerial dry weight with 1.76 g; in the radical part, X3 stood out with 0.16 g; genotype X5 obtained the highest total value with 1.86 g.

#### **Discussions**

In relation to the electrical conductivity of the soil at 60 days, it was observed that the substrates used for the evaluation of the controls (0 mM NaCl) showed a value of 2.30 dS/m, indicating a slight degree of salinity, the reason could be that at 55 days of the study the plants

of the experiment were fertilized, thus increasing the concentration of salts in the soil. Therefore, the substrates irrigated with the saline solution (300 mM NaCl) reached a very high degree of salinity with an electrical concentration of 11.32 dS/m, being called a strongly saline soil. This result may also be due to the fact that NaCl salts, due to their high solubility, remain in the soil solution, which are transported with the water to the surface by capillary rise and once the water evaporates, they accumulate on the soil surface increasing the salt content (Richard, 1965).

Regarding the emergence rate, the genotypes that stood out with dose 2 (300 mM NaCl) were 36, 42, 48, 49, O-7 and X3 with an average of 100%, while the genotypes with dose 1 (0 mM NaCl) registered the lowest values despite being the same genotypes, genotypes 36 and 42 obtained an average of 86.67%, genotype 48 with 80%, 49 with 73.33%, O-7 with 40% and X3 with 80%. This is due to the fact that NaCl deficiency presented a delay in the physiological mechanisms involved in the initial stage of germination and therefore in plant emergence, as mentioned by (Miranda et al., 2017).

On the other hand, regarding the relative water content in the leaves, a constant could be observed in the genotypes with both doses of NaCl applied in this experiment, which coincides with the research conducted by (La Rosa et al., 2008) in their study response of quinoa to saline conditions where their RLWC results do not show significant variations during the evaluations at a concentration of 300 mM in the seedling stage. In this sense (Jacobsen et al., 2003) note that quinoa has demonstrated the capacity to accumulate salt ions in its tissues in order to control and adjust the water potential in the leaf, which allows the plants to maintain cell turgor and regulate transpiration under saline conditions, avoiding physiological damage from drought and therefore death.

It should be noted that the genotypes that achieved the best records in RLWC showed a vigorous appearance, with dark green leaf coloration and erect stems, providing evidence that quinoa behaves as a halophyte species (Chilo et al., 2009). A genotype with the ability to minimize stress by conserving turgor in leaves in environments under stress will have physiological advantages, i.e., it allows turgor-

dependent processes such as growth and somatic activity to take place, in addition to protecting and maintaining the photosystem complex, as indicated by (Pask et al., 2012).

On the other hand, when analyzing the root length response across all treatments, it can be suggested that the 300 mM NaCl concentration induced root elongation. In their study on quinoa's response to drought, cold, and salinity, Zurita & Ruiz (2014) observed that the roots exhibited a fishbone-like morphology, indicating a more pronounced reduction in the growth of lateral roots compared to primary roots. They concluded that this primary root elongation serves as an adaptive mechanism for deeper and more reliable water acquisition, thus enhancing the plant's ability to cope with saline conditions. In terms of aerial, root and total fresh weight, the genotypes O-4 with 32.67 g, X4 with 4 g and O-4 with 36.34 g, respectively, stood out. While the genotypes under salt stress showed averages much lower than the previous ones. Aragón, cited by (Miranda et al., 2017), stated that plants under salt stress close their stomata, which causes a reduction in photosynthetic activity and therefore a lower biomass production, for this reason, the treatments under NaCl induction obtained the lowest values.

Finally, the genotypes that excelled under salt stress in terms of aerial, root and total dry weight were X5, X3 and X5, respectively. In this regard (Zurita & Ruiz, 2014) mention that when water absorption or water transport by xylem conductive tissues is insufficient to satisfy evapotranspiration, as occurs in cases of water deficit, plants affect both their growth (dry matter accumulation decreases) and their phenology (life cycle is accelerated). For this reason, the treatments under NaCl induction obtained the lowest values.

## CONCLUSIONS

The percentage of emergence of quinoa plants under the addition of sodium chloride was not affected by the levels of salts in the irrigation water; rather, it favoured emergence by showing a slight increase over the control value, even though they are the same genotypes. The genotypes that were established in the saline medium showed lower values of relative water content than those grown under normal con-

ditions, indicating that under these conditions the water content decreases. In relation to tolerance, genotypes X4, O-10, X3, O-1, X5, O-2, O-5, O-3 showed good development under salt stress during the course of the research, registering the highest percentages of RLWC within a range of 53-70%.

The effect of NaCl caused an elongation of the main root as the concentration of salts in the soil increased with daily irrigation during the different crop phenophases, in addition to considerably reducing root volume. X3 was the genotype affected with a root length of 40 cm and genotype O-10 with 5.40 cm<sup>3</sup> had the smallest volume occupied by the root system in the soil. The excessive accumulation of harmful salts in the soil caused a lower biomass production in the evaluated plants. Genotype X5 was the most outstanding, obtaining a higher biomass accumulation during the 60 days of study compared to the other 29 genotypes, obtaining an average of 12.33 g in fresh matter and 1.86 grams of dry matter, reaching a higher total biomass production than the other NaCl treatments.

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