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# Performance of quinoa cultivars grown on saline-alkaline soil

**Abstract** – The objective of this work was to evaluate the seed yield and quality of seven quinoa cultivars grown on nonsaline and saline-alkaline soil. The following cultivars were evaluated: Titicaca (Denmark), Sandoval Mix (UK), Moqu-Arrochilla (Peru), Rainbow (USA), Red Head (USA), French Vanilla (USA), and Oro De Valle (USA). A randomized block experimental design was carried out, for two years. Plant height, stem thickness, seed, and stem yields, crude protein, and raw ash were determined. Seed, raw ash, and stem crude protein contents increased on saline-alkaline soils, while the yield components decreased. Accordingly, the highest stem thickness, 1000-grain weight, seed, straw, and biological yields were observed in French Vanilla, Titicaca, Rainbow, and Sandoval Mix on nonsaline soils, respectively. However, Oro De Valle, and Moqu Arrochilla had higher stem crude protein and seed raw ash contents on saline-alkaline soils, respectively. Among the cultivars, French Vanilla showed a lower decrease of seed yield and a higher increase of harvest index on saline-alkaline soils than on nonsaline ones. Saline-alkaline soils decrease the seed yield and quality characteristics of quinoa cultivars; however, Titicaca and Moqu Arrochilla show a higher seed yield and quality performance in this condition.

**Index terms**: *Chenopodium quinoa*, abiotic stress, quality value, seed yield.

## Desempenho de cultivares de quinoa cultivadas em solo salino-alcalino

**Resumo** – O objetivo deste trabalho foi avaliar o rendimento de sementes e a qualidade de sete cultivares de quinoa cultivadas em solo não salino e salino-alcalino. As cultivares avaliadas foram Titicaca (Dinamarca), Sandoval Mix (Reino Unido), Moqu Arrochilla (Peru), Rainbow (EUA), Red Head (EUA), French Vanilla (EUA) e Oro De Valle (EUA). O experimento foi realizado em delineamento de blocos ao acaso, por dois anos. Altura da planta, espessura do colmo, rendimentos de sementes e colmos, proteína bruta e cinza bruta foram determinados. Os teores de cinza bruta da semente e proteína bruta do colmo aumentaram em solos salino-alcalinos, enquanto os componentes do rendimento diminuíram. Consequentemente, a maior espessura de colmo, massa de 1000 grãos, sementes, palha e rendimentos biológicos foram observados nas cultivares French Vanilla, Titicaca, Rainbow e Sandoval Mix em solos não salinos, respectivamente. No entanto, as cultivares Oro De Valle e Moqu Arrochilla apresentaram maior teor de proteína bruta do caule e de cinza bruta da semente em solos salinos-alcalinos, respectivamente. Além disso, entre as cultivares, French Vanilla apresentou a menor redução da produção de sementes e o maior aumento do índice de colheita em solos salino-alcalinos do que em solos não salinos. Solos salino-alcalinos diminuem o rendimento de sementes e as características de qualidade das cultivares de quinoa, porém, nessas condições, Titicaca e Moqu Arrochilla apresentam maior rendimento de sementes e melhor qualidade.

**Termos para indexação**: *Chenopodium quinoa*, estresse abiótico, qualidade de semente, rendimento de semente.

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## Introduction

Over 1,000 million hectares of agricultural areas in the world are affected by salinity (400 million ha) and alkalinity (450 million ha) (FAO, 2015). Currently, 62 million ha of the irrigated areas in the world are affected by salinity (Khamraliev et al., 2023), and this rate is increasing daily. Due to increasing salinity, the number of cultivars of species that can be grown in agricultural areas are restricted, and the quantity and quality of the products obtained decrease.

In this sense, plants that can grow in saline conditions and used mainly as a food source and feed have been seen as an important advantage. One of these species is *Chenopodium quinoa* Willd., which can tolerate salinity, drought, and frost (Akçay & Tan, 2019; Maamri et al., 2022; Keskin et al., 2023). Quinoa, an annual herbaceous species, can quickly grow in poorly drained, low-fertility, alkaline, and acidic soils. Some cultivars can even survive when irrigated at salt concentrations similar to those found in seawater; they can withstand high salinity levels (40 dS $m^{-1}$) in the root zone (Adolf et al., 2013; Eisa et al., 2017). However, the quinoa degree of tolerance to salinity may vary, depending on cultivars and on applied salinity levels (Akçay & Tan, 2019; Keskin et al., 2023). If the cultivars' ability to adapt to salinity can be shown, agricultural areas affected by salinity and alkalinity can be brought into production more effectively with suitable quinoa cultivars.

Quinoa farming has become widespread in the last 25 years, and it is grown in more than 90 countries worldwide. Quinoa stands out as a food with high protein content (13.3–20.0%) and quality (good amino acid balance) of its gluten-free seed (Vidueiros et al., 2015). Its seed are rich in vitamins and minerals and have a high fiber quality, thus playing an important role as a food resource in human nutrition (Demir & Kilinc, 2016; Kir & Temel, 2016). In addition, after seed harvesting, quinoa seed, grass, silage, and harvest residues (leaves and stalks) show high nutritional, chemical, mineral, and vitamin content and can meet the feed needs of animals (Tan, 2020; Temel & Keskin, 2020; Temel & Tan, 2020; Temel, 2021; Güner & Temel, 2022).

Most previous studies on salinity in quinoa plant focused on germination and seedling development characteristics under controlled conditions (Akcay & Tan, 2019; Stoleru et al., 2019; Qureshi & Daba, 2020). However, it has been determined that the number of studies showing the quinoa plant performance in field conditions with saline-alkaline soil characteristics, especially its seed yield and quality characteristics, is quite limited (Eisa et al., 2017).

The objective of this work was to evaluate the seed yield and quality performance of seven quinoa cultivars subjected to nonsaline and saline-alkaline soils.

## Materials and Methods

The research was carried out in 2021 and 2022, in Iğdir, at 39°55'42"N, 44°05'33"E (control) and at 39°55'44"N, 44°05'40"E (saline soil), at 853 m altitude, in Northeastern Turkey. The experimental area has a semiarid steppe climate (Köppen, 1918). Temperature and precipitation values of the region for the long-term mean are presented for 2021-2022, during the growing period of the plants (Figure 1) (GDM, 2023).

Saline-alkaline (EC 9.69 $dSm^{-1}$, pH 9.80) and nonsaline (EC 2.05 $dSm^{-1}$, pH 8.41) (control) soils were used in the experiment. The soils are classified as Inceptisols order, Xerepts suborder, and Haploxerepts great soil group (FAO, 1988). The experiments were performed in the irrigated land conditions of Iğdır University, Agricultural Application and Research Center.

Soil samples (0–0.30 m) were taken before sowing, and soil analyses were performed (Table 1). Cultivar names used in the present study as crop material are: Titicaca (Denmark), Sandoval Mix (United Kingdom), Moqu Arrochilla (Peru), Rainbow (United States of America), Red Head (United States of America), French Vanilla (United States of America), and Oro De Valle (United States of America). The experiment was conduct in a randomized block design and set up in both soil conditions, with three replicates. Each parcel area was planned as 8.75 $m^2$ (1.75x5.0 m), and 2.0 m spacing was left between parcels.

In both experimental years, sowings were carried out on April 2. Seed were sown by hand at 0.02 m soil depth, in lines opened with a marker, at 0.10 m intra row and 0.35 m inter-row spacings. Fertilizers – 80 kg $ha^1$ P (43-44% triple-super phosphate) and 80 kg $ha^{-1}$ N (21% ammonium sulfate) – were annually applied to plants, during the preparation of the seedbeds. Additional 50 kg $ha^{-1}$ N was also applied when plants reached 0.30 m height. Irrigation was performed when 50% of the


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available water supply in the soil depleted (between April and August).

Quinoa harvest was carried out when seed reached physiological maturity (R12). During the harvest, 0.5 m part from the plot beginnings and one row from the plot edges were removed, as edge effects and measurements (plant height and stem thickness) were made on ten randomly selected plants in the remaining area. Then, the remaining plants in the plot were cut at 0.10 m height above the soil level and dried in a drying oven set at 40°C. After drying, the plants were weighed on a precision scale, and their biological yields were determined. Then, the plants were threshed, and seed and stem (straw) yields were determined (kg $ha^{-1}$). Afterward, harvest indices were determined by proportioning seed yields to biological yields, the sum of straw and seed yield. One hundred seed from each harvested cultivar were counted in four replicates and weighed on a precision scale. Then, 1000-grain weight (g) were calculated by taking the average and multiplying by 10 (Kir & Temel, 2016). For chemical analysis, dried stems and seed were ground separately in a Wiley Mill, to pass through 1 mm sieve. Then, using the ground samples, stem and seed crude protein ratios were determined according to the micro-kjeldahl method. Finally, 1 g of ground seed samples were burned for 8 hours in a muffle furnace set at 550°C, and their raw ash ratio was detected (Latimer, 2019).

The results were subjected to the analysis of variance according to a randomized block split-plot design, using the JMP 5.0.1 package program (JMP, A Business Unit of SAS, Cary, NC), with year replicates. The means found to be significant were compared using the LSD test, at 5% probability.

## Results and Discussion

The evaluation vegetative and yield traits of quinoa showed significant differences among year, soil types, and cultivars (Table 2). The highest plant height, stem thickness, straw, seed, and biological yields were determined in 2022. These differences can be attributed to the difference of climatic conditions, especially for the amount of precipitations, from year to year (Figure 1). According to Taiz & Zeiger (2010), excess rainfall during the vegetative period increases biomass yield by encouraging the robust growth of quinoa. In contrast, excess rainfall, during the generative stage, reduces pollen viability, reducing healthy fertilization and therefore seed yield (Ceccato et al., 2011). As observed in the current research, the amount of precipitation falling in April-June (2022) was high, which is period when quinoa carries out its vegetative development intensively, and in July (2021), when it provides its generative development.

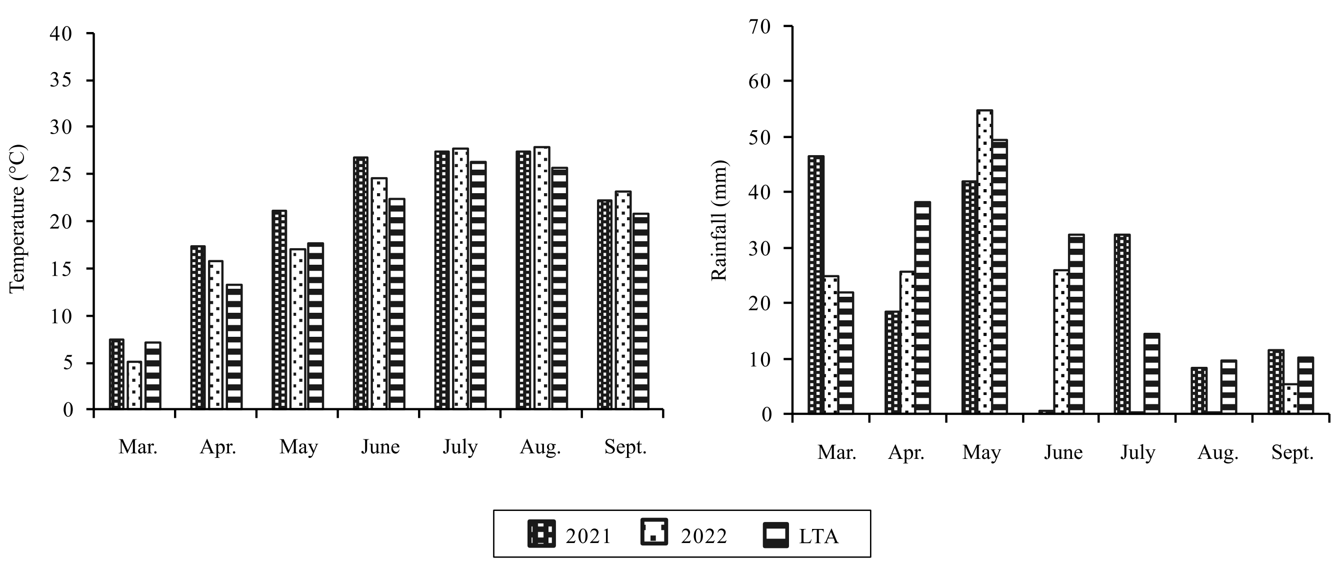


**Figure 1.** Temperature and rainfall in the quinoa (*Chenopodium quinoa*) experimental area, during 2021-2022. LTA: long-term average.

Values for stem thickness, plant height, stem, seed, and biological yields of quinoa decreased in saline-alkali soils, in comparison with nonsaline ones (Table 2). This may be due to the fact that the environmental conditions, especially the chemical and physical structure of the soil (that is, texture, aggregate, and bulk density) is not suitable for water and nutrient uptake by plants in saline-alkali soils (Lakhdar et al., 2009). Previous studies have also shown that plant height, stem thickness, seed, stem, and biological yields of quinoa decreased with increasing salt concentration (Dumanoglu et al., 2016). As a matter of fact, Eisa et al. (2017) reported that the seed yield of quinoa in saline soils (ECe 17.9 dS $m^{-1}$) decreased by 61.7%, in comparison with nonsaline conditions. Karyotis et al. (2003) stated that quinoa seed yield in saline-alkaline soils decreased by 54.6%. Iqbal et al. (2019) stated that quinoa seed and biological yields in saline-alkaline conditions (pH 8.8 and ECe 13.9 dS $m^{-1}$) decreased by 17.93% and 28.71%, respectively. In the present study, determinations showed that seed

**Table 1.** Physical and chemical characteristics of nonsaline and saline-alkaline soils.

| Soil characteristic | Saline-alkaline soil | | Nonsaline soil | |
|---|---|---|---|---|
| | Value | Classification | Value | Classification |
| Saturation (%) | 59.41 | Clay loam* | 63.16 | Clay loam* |
| Organic matter (%) | 0.93 | Very little* | 0.87 | Very little* |
| Electrical conductivity (EC, dS $m^{-1}$) | 9.69 | Very saline** | 2.05 | Nonsaline** |
| pH | 9.80 | Very strong alkaline** | 8.41 | Medium alkaline** |
| Exchangeable sodium percentage (ESP, %) | 28.0 | High** | 0.55 | Low** |
| Calcareous. (%) | 11.25 | Medium calcareous* | 9.38 | Medium calcareous* |
| Potassium (kg $ha^{-1}$) | 288.6 | Medium* | 278.4 | Medium* |
| Phosphorus (kg $ha^{-1}$) | 49.9 | Little* | 47.7 | Little* |

*Classification according to Ulgen & Yurtseven (1995). **Classification according to Richards (1954).

**Table 2.** Means of plant height, stem thickness, seed, straw, and biological yields of seven quinoa (*Chenopodium quinoa*) cultivars grown in different soil types[(1)].

| Factor | Plant height (m) | Stem thickness (mm) | Seed yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) | Biological yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|
| Cultivars | | | | | |
| French Vanilla | 1.00a | 10.93a | 1737.3d | 5563.5c | 7300.8c |
| Moqu Arrochilla | 0.68d | 8.65d | 1602.0e | 4835.7d | 6437.7d |
| Oro de Valle | 0.97b | 10.27b | 1737.0d | 5374.6c | 7111.6c |
| Rainbow | 0.95bc | 9.03c | 2190.5b | 6072.5b | 8263.0b |
| Red Head | 1.02a | 10.40b | 1856.0c | 6228.1b | 8084.0b |
| Sandoval Mix | 0.92c | 10.22b | 1562.5e | 8066.6a | 9629.1a |
| Titicaca | 0.67d | 6.59e | 2459.0a | 3380.2e | 5839.2e |
| SEM | 1.08** | 0.07** | 26.8** | 142.7** | 147.3** |
| Soil types | | | | | |
| Saline-alkaline | 0.82b | 8.86b | 1552.7b | 4668.8b | 6221.5b |
| Nonsaline | 0.95a | 10.02a | 2202.8a | 6622.9a | 8825.7a |
| SEM | 0.79** | 0.04** | 23.9** | 48.6** | 39.7** |
| Years | | | | | |
| 2021 | 0.86b | 9.09b | 1808.5b | 5395.7b | 7204.2b |
| 2022 | 0.91a | 9.79a | 1947.1a | 5896.0a | 7843.1a |
| SEM | 0.79** | 0.04** | 23.9** | 48.6** | 39.7** |

[(1)]Means followed by different letters, in the columns, differ by the LSD test, at 1% probability. **Significant at 1% probability. SEM, standard error of the mean.

and biological yields of quinoa decreased by 29.51% and 29.23%, respectively, in saline-alkaline soils.

French Vanilla and Red Head had a higher plant height than the other cultivars, and French Vanilla had the greatest stem thickness (Table 2). The highest seed yield was determined in Titicaca cultivar, and straw and biological yields, in Sandoval Mix cultivar. These results can be attributed to the difference of genetic structures of cultivars from different ecotypes or countries. Similar results were obtained in cultivars originating from different countries, which subjected to saline-alkaline soil conditions (pH: 8.6-8.9 and ECe 6.5-20 dS m$^{-1}$); the authors' reports showed that plant height, stem thickness, seed yield, and biological yields of the cultivars varied between 0.48-0.86 m, 6.0-16.3 mm, 421.4-4,547.6 kg ha$^{-1}$, and 1,239-7,211 kg ha$^{-1}$, respectively (Karyotis et al., 2003; Ebrahim et al., 2018; Iqbal et al., 2019; Mohamed et al., 2019; Qureshi & Daba, 2020).

The characteristics evaluated in all cultivars decreased in saline-alkaline soils in comparison with nonsaline ones; however, the decrease rates differed according to the cultivars (Figure 2). This fact caused the binary interaction to be significant. These differences may be attributed to the fact that cultivars originating from different ecotypes react differently to environmental conditions, due to their different genetic structures. Five different quinoa ecotypes (Altiplano, Coastal, Inter-Andean valleys, Salares-Salt Flat, and Yungas) have been identified, according to their origins and plant characteristics (Fuentes et al., 2012).

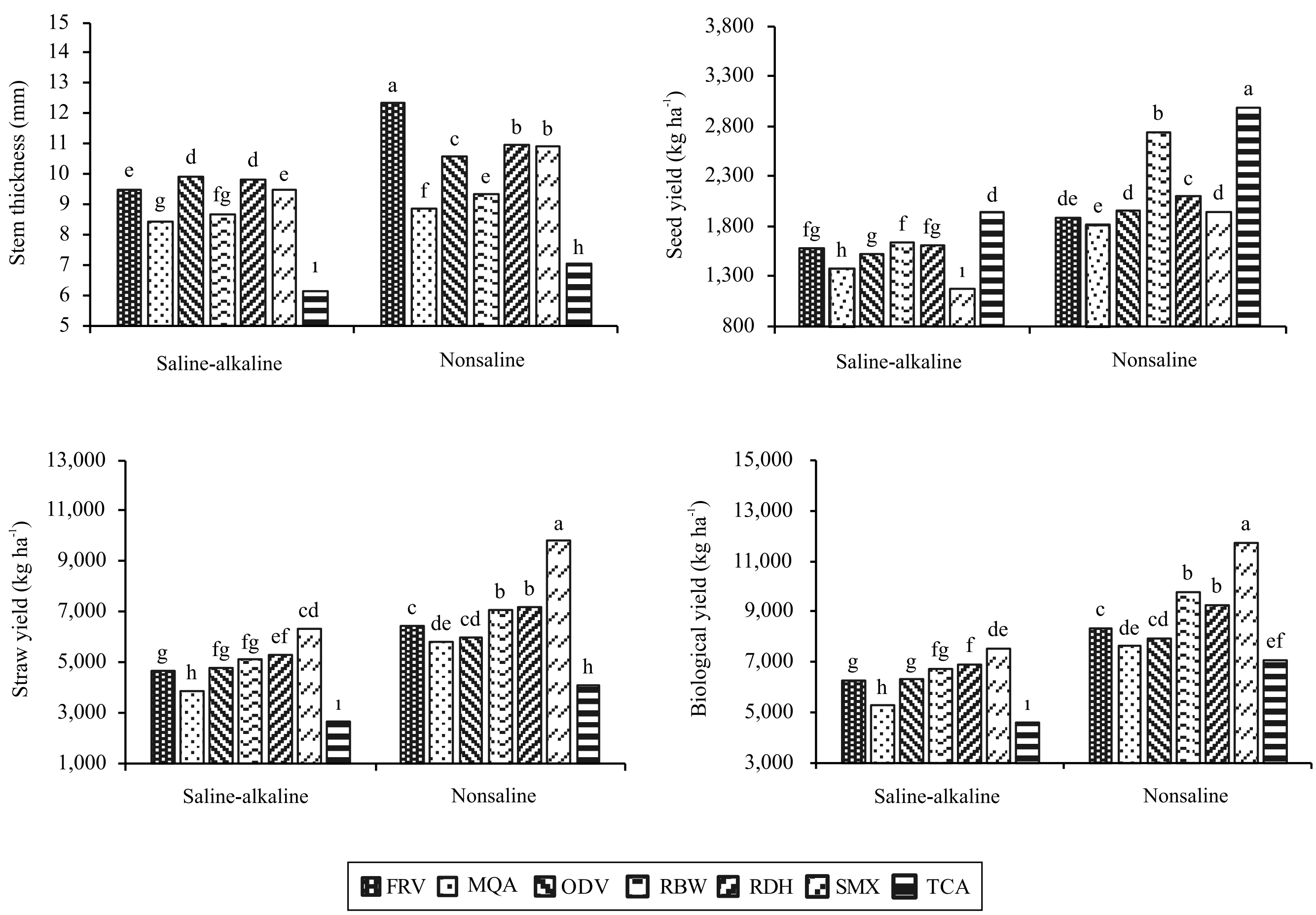


**Figure 2.** Changes in quinoa (*Chenopodium quinoa*) stem thickness, seed yield, straw yield, and biological yield according to cultivar and soil types. Bars followed by different letters are significantly different, by the LSD test, at 1% probability. Cultivars: FRV, French Vanilla; MQA, Moqu Arrochilla; ODV, Oro de Valle; RBW, Rainbow; RDH, Red Head; TCA, Titicaca; SMX, Sandoval Mix.


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The effects of years (except for crude protein and raw ash), soil types (except for harvest index), and cultivars, on the studied parameters, were found to be statistically significant (Table 3). The increase rate of biological yield in 2022 was higher than that of seed yield, which caused the harvest index to be higher in 2021. The harvest index is a value obtained by the ratio of seed yield to biological yield. In 2021, the parameter 1000-grain weight was found to be lower, and the stem crude protein content was higher. The high amount of rainfall in July 2021 (Figure 1), when flowering was intense, may have caused the 1000-grain weight to be lower in 2021. The excess rainfall during the flowering period reduces the pollen viability of quinoa and prevents fertilization from occurring healthily (Ceccato et al., 2011). The rainfall during the vegetative period in 2022 caused the plants to grow more vigorously and to form thicker stems. Thick stems cause increases in the amounts of structural substances, such as cellulose and lignin, and decreases in the amounts of nonstructural carbohydrates and proteins (Onal Asci & Acar, 2018; Temel & Yolcu, 2020). For these reasons, the stem crude protein ratio is thought to be lower in 2022.

The parameters 1000-grain weight and crude protein content decreased in saline-alkaline soils, in comparison with nonsaline soils (Table 3). The decrease of crude protein content may have resulted from the inability of plants to absorb sufficient water and nutrient intake in saline-alkaline soils, since plants absorb less water and nutrients in saline-alkaline soil conditions, thus resulting in the osmotic retention of water. Consequently, ion imbalance occurs in the cell protoplasm, thus protein synthesis is inhibited, and the HP rate decreases (Taiz & Zeiger, 2010). Mohamed et al. (2019) stated that the highest salt application increased the seed weight in quinoa. Dumanoglu et al. (2016) reported the increasing of salt concentrations resulted in the decrease of the grain HP content of quinoa. In contrast, Eisa et al. (2017) reported that increasing salt concentrations, up to a specific dose, increased or did not change the seed protein content.

The stem crude protein content increased in saline-alkaline soils, which can be due to the fact that plants in saline-alkaline soils have a lower plant height and stem thickness (Table 2). This is because thin stems have higher intracellular components, such as protein, sugar, and fat, than those in thick stems (Onal Asci & Acar, 2018).

**Table 3.** Means of harvest index, 1000-grain weight, seed crude protein, stem crude protein, and seed raw ash rates of quinoa (*Chenopodium quinoa*) cultivars grown in different soil types[(1)].

| Factor | Harvest index (%) | 1000-grain weight (g) | Seed crude protein (%) | Stem crude protein (%) | Seed raw ash (%) |
|---|---|---|---|---|---|
| Cultivar | | | | | |
| French Vanilla | 24.14cd | 2.53a | 15.58bc | 9.18b | 4.74bc |
| Moqu Arrochilla | 25.27bc | 2.47a | 16.66a | 7.83c | 5.53a |
| Oro De Valle | 24.49cd | 2.41a | 16.73a | 10.04a | 4.78b |
| Rainbow | 26.44b | 2.53a | 14.35d | 7.11d | 4.40e |
| Red Head | 23.07d | 2.44a | 16.09ab | 7.13d | 4.00d |
| Sandoval Mix | 16.21e | 1.87b | 15.09cd | 6.81d | 4.32de |
| Titicaca | 42.14a | 2.50a | 13.55e | 8.78b | 4.96b |
| SEM | 0.50** | 0.05** | 0.28** | 0.21** | 0.13** |
| Soil type | | | | | |
| Saline-alkaline | 26.04 | 2.23b | 14.98b | 8.60a | 5.14a |
| Nonsaline | 25.89 | 2.55a | 15.89a | 7.65b | 4.21b |
| SEM | 0.12$^{ns}$ | 0.01** | 0.12** | 0.16** | 0.03** |
| Years | | | | | |
| 2021 | 26.15a | 2.31b | 15.47 | 8.63a | 4.69 |
| 2022 | 25.78b | 2.47a | 15.40 | 7.62b | 4.66 |
| SEM | 0.12** | 0.01** | 0.12$^{ns}$ | 0.16** | 0.03$^{ns}$ |

[(1)]Means followed by different letters, in the columns, differ by the LSD test, at 1% probability. $^{ns}$Nonsignificant. **Significant at 1% probability. SEM, standard error of the mean.


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In the evaluation of the cultivars, the highest harvest index was determined in Titicaca, stem crude protein content in Oro De Valle, and seed ash content in Moqu Arrochilla. In the comparison with other cultivars, Sandoval Mix had a lower 1000-grain weight, while Moqu Arrochilla and Oro De Valle showed a higher seed crude protein content (Table 3). These results may have been due to differences among the cultivars. Ebrahim et al. (2018) stated that in Cıca and Real cultivars originating from different countries, the parameter 1000-grain weight varied between 4.0-5.8 g, the seed crude protein content between 12.80-13.60%, and the seed raw ash content between 5.63-6.41%. Regarding the subject in studies conducted under field conditions with saline-alkali soil characteristics, Karyotis et al. (2003) reported that seed crude protein content in eight quinoa cultivars varied between 17.41% and 19.3%; and Qureshi & Daba (2020) reported that harvest index in five quinoa genotypes varied between 37.44% and 41.11%.

The effect of cultivar x soil type interaction was statistically significant for 1000-grain weight, harvest index, seed raw ash, and stem crude protein content (Figure 3). This may be due to the fact that cultivars with different genetic structures respond differently to environmental conditions. For instance, while the 1000-grain weight of French Vanilla cultivar increased by 6.12% in saline-alkaline soils compared to nonsaline ones, the 1000-grain weight of other cultivars showed a decrease between 7.69% and 24.86%. However, while the harvest indices of Titicaca and Sandoval Mix cultivars were in the same statistical group according to soil types, the harvest indices of French Vanilla, Moqu Arrochilla, and Red Head cultivars increased

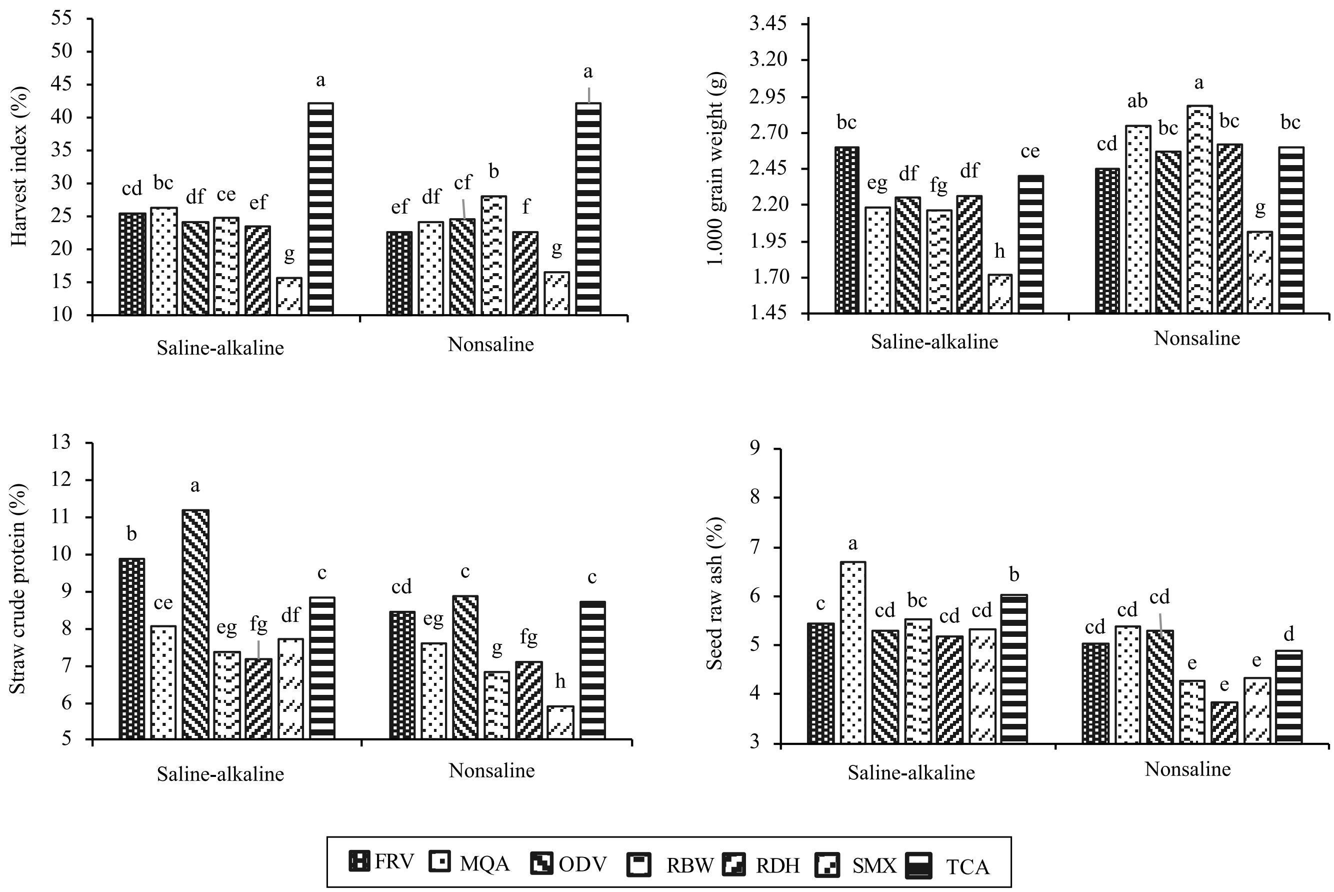


**Figure 3.** Change in 1000-grain weight, harvest index, stem crude protein, and seed raw ash rate according to quinoa (*Chenopodium quinoa*) cultivar and soil types. Bars followed by different letters are significantly different according to LSD test at 1% probability. Cultivars: FRV, French Vanilla; MQA, Moqu Arrochilla; ODV, Oro de Valle; RBW, Rainbow; RRH, Red Head; TCA, Titicaca; and SMX, Sandoval Mix.


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between 3.20% and12.51% in saline-alkaline soils, and decreased between 1.84% and 12.11% in the other two cultivars.

## Conclusions

1. The quinoa (*Chenopodium quinoa*) cultivars studied can be easily cultivated in saline-alkaline soils.
2. The quinoa cultivars show varied responses according to soil salinity, regarding seed yield and quality performance.
3. In saline-alkaline soils, Titicaca cultivar can be preferred for seed production, and Sandoval Mix cultivar, for stem and biological yields.

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