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Using Agronomic Parameters to Rate Quinoa (*Chenopodium quinoa* Willd.) Cultivars Response to Saline Irrigation under Field Conditions in Eastern Morocco †

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Abstract: Salinity is becoming a serious threat to global food security, as it can significantly reduce crop yields and irreversibly damage soil fertility. Moreover, this problem is currently exacerbated by the impact of climate change, especially in drylands. Hence, introducing and adapting salinity-tolerant species, such as quinoa (*Chenopodium quinoa*, Willd.), could be among the ways to enhance the value of saline land, increasing its productivity and improving small farmers' income in rural areas. Quinoa, originally cultivated in the Andean region, has gained more attention throughout the Mediterranean region because it yields well even in marginal soils. It is also considered one of the world's healthiest foods, as its grains contain a balanced composition of minerals, vitamins, dietary fiber, fats, and high-quality, gluten-free proteins, with a balanced profile of all amino acids. In Morocco, quinoa was introduced in 2000, but its expansion is still limited to certain regions. In Eastern Morocco, for the first time, an experiment was carried out in 2019–2020 aiming to assess the response of five quinoa cultivars (INIA-420 Negra, Titicaca, Puno, ICBA-Q4 and ICBA-Q5) to saline irrigation. For this, we used two levels of water irrigation salinity: 1.50 $dS.m^{-1}$ as a no-salt control from Tagma's source in Tafoghalt village and 10.5 $dS.m^{-1}$ as salt treatment from local water drilling. Agronomic parameters, mainly dry matter, leaf area, grain yield and 1000-kernel weight, were measured to assess quinoa cultivars' responses to saline irrigation. Statistical analysis revealed that all investigated parameters were significantly affected by salinity, quinoa variety and their interaction ($p < 0.05$). Furthermore, significant differences in terms of salinity tolerance among the five quinoa cultivars were observed, with the highest (2.17 $t.ha^{-1}$) and lowest (0.33 $t.ha^{-1}$) yields recorded for ICBA-Q5 and INIA-420 Negra, respectively. However, the same varieties tested previously in Southern Morocco tolerated a higher level of salinity (12 $dS.m^{-1}$). We assume that other factors interfered with salinity and variety, such as the sowing date, which was relatively late and exposed the flowering and grain filling stages to high heat in May and June.

Keywords: quinoa cultivars; saline irrigation; tolerance; yield; Eastern Morocco

1. Introduction

Nowadays, achieving food security for a growing population is a worldwide priority, especially in resource-poor and degraded marginal lands where agricultural productivity is still limited by continuous soil and water salinization [1]. Indeed, high salinity levels could substantially and irreversibly decrease biodiversity, as many crops are not able to grow in saline conditions. Salt-resilient crops such as quinoa could be considered as an alternative to current staple crops to sustain agricultural production, especially under saline irrigation [2,3].

Recently, quinoa (*Chenopodium quinoa*, Willd.), a facultative halophyte, has been drawing increasing interest worldwide given its high nutritional value and its capacity to enhance food security by tolerating environmental constraints such as frost [4], drought [5,6] and salinity [7–9]. In Morocco, quinoa was introduced in 2000, but its expansion is still limited to certain regions and few adapted genotypes. In Eastern Morocco, for the first time, a study was conducted in 2019–2020 aiming to investigate and assess the response of five quinoa cultivars to saline irrigation and to set up sustainable and suitable technical practices for local farmers in this rural area.

2. Materials and Methods

2.1. Experimental Site

This study was carried out on a farm located in the rural municipality of Boughriba in Berkane Province, 29.3 km from the Mediterranean Sea, towards the north east of Morocco (X = 769.014°; Y = 473.689°; Z = 526 m). The soil presented a silt loam texture with 1.45% organic matter, a pH of 7.3 and a CE of 0.8 dS.m^{-1}. The climate is semi-arid, with an irregular rainfall averaging 290 mm per year (average calculated from weather station data of Boughriba over a series of 30 years). During 2020, the total rainfall was 210 mm and the average temperature ranges from 10.7 to 26.1 °C, while the maximum and the minimum temperatures varied from 17.4 to 34 °C and from 3.9 to 20.3 °C, respectively (Figure A1).

2.2. Trial Setup

We laid out a field experiment in a split-plot design with three replicates, applying five quinoa cultivars in the main plots and two salinity levels of irrigation water in the subplots. The cultivars were INIA 420-Negra, Titicaca, Puno, ICBA-Q4, and ICBA-Q5, and have previously been tested in the Rhamna region in south Morocco. The irrigation water salinity levels were based on two available groundwater resources namely, Tagma's source in Tafoghalt village as a control treatment and water drilling as a salt treatment. The respective electrical conductivity EC values were approximately 1.5 dS.m^{-1} and 10.5 dS.m^{-1}. We used drip irrigation with a flow rate of 2 L.h^{-1}. The sowing and harvesting dates, respectively, occurred on 13 March and 10 July. Regarding fertilization, all treatments received the same quantity of local manure before the sowing date. The surface of the unit plot was 12 m^2 (4 m × 3 m), and each consisted of seven rows with a 50 cm interline distance and a 30 cm interplant distance.

2.3. Sampling Procedure and Measured Parameters

During quinoa's growth cycle, one sample was taken in each phenological stage, mainly in the vegetative, flowering and grain filling stages, to measure agronomic parameters. These samplings occurred, respectively, on 50, 75 and 90 days after sowing. The monitored parameters were quinoa height, number of leaves, leaf area, and the fresh and dry weight of roots, leaves and the whole plant. The sampling area was 1 m^2 per replication, in which 9 to 10 plants were manually cut and transferred to the laboratory of the National Institute of Agronomical Research in Berkane. At harvest, kernels were dried in an oven at a temperature of 110 °C until their weight stabilized. Then, final dry matter, seed yield and 1000-kernel weight were assessed.

2.4. Statistical Analysis

Statistical analysis was performed using SAS 9.0 software. For a better interpretation, a two-way analysis of variance (ANOVA) was used to assess the effects of irrigation water salinity level, quinoa variety and their interaction on monitored parameters. When ANOVA was significant ($p < 0.05$), Student's test (LSD) was used for means comparison ($p \leq 0.05$).

3. Results and Discussion

3.1. Results

3.1.1. Agronomic Parameters during Quinoa Growth Cycle

All varieties achieved their growth cycle and developed differently depending on the salinity level of the irrigation water and variety. Analysis of variance (ANOVA) showed the significant effects of the two factors and their interaction on most measured parameters mainly in flowering and grain filling stages. Contrary, no significant effect was recorded on the leaf area in the last stage ($p < 0.05$) (Table 1). The assessed parameters were quinoa vegetative height (VH), root dry matter (RDM), leaf dry matter (LDM), total dry matter (TDM), leaf number (LN) and leaf area (LA).

Table 1. Variation of agronomic parameters during the quinoa growth cycle.

Parameters	**VH (cm)**			**RDM (g/Plant)**			**LDM (g/Plant)**			**TDM (g/Plant)**			**LN**			**LA (cm^2)**		
DAS	50	75	90	50	75	90	50	75	90	50	75	90	50	75	90	50	75	90
Salinity (S)	ns	***	***	*	***	***	**	***	ns	***	***	***	***	***	***	***	*	ns
Variety (V)	***	***	***	ns	***	***	*	***	***	***	***	***	***	***	***	***	*	ns
(S) × (V)	ns	***	***	**	***	***	ns	***	***	***	***	***	***	***	***	***	*	ns

ns: no significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.1.2. Growth Parameters

The main results of the ANOVA for the investigated parameters are recorded in Table 2. At harvest time, the studied parameters were final dry matter, grain yield and 1000-kernel weight (1000 KW). The statistical analysis revealed that salinity, variety and their interaction affected significantly most parameters, except 1000 KW ($p < 0.05$).

Table 2. Analysis of variance (GLM procedure) of the effect of salinity, variety and their interaction on post harvesting parameters.

Factors	**DF**	**Dry Matter (g/plt)**	**Kernel Yield (t/ha)**	**1000 Kernel Weight (g)**
Salinity (S)	1	0.00 ***	0.00 ***	ns
Variety (V)	4	0.00 ***	0.00 ***	ns
Interaction (S × V)	4	0.00 ***	0.016 *	ns

ns = not significant, * denotes $p < 0.05$ and *** denotes $p < 0.001$.

3.1.3. Total Dry Matter and Grain Yield

Final dry matter (g/plant) and grain yield ($t.ha^{-1}$) were significantly affected by irrigation water salinity level (10.5 $dS.m^{-1}$) comparatively to the control (1.5 $dS.m^{-1}$) for all varieties ($p < 0.05$). Generally, a substantial decrease in dry matter and grain yield was recorded. However, this reduction depended on variety and was more noticeable for Titicaca (68%) and INIA-420 Negra (64%) in terms of dry matter and for Puno (48%) and Titicaca (46%) regarding grain yield ($p \leq 0.05$). Moreover, the average yield comparison showed that the best results were recorded for ICBA-Q5, with minimum loss (21%) when it was irrigated with saline water (10.5 $dS.m^{-1}$) ($p \leq 0.05$) (Table 3).

Table 3. Final dry matter and kernel yield according to water irrigation salinity level and quinoa variety.

CE ($dS.m^{-1}$)	Variety	Final Dry Matter (g/Plant)	Grain Yield (t/ha)
1.50	INIA 420-Negra	148.30 ± 4.97 **a**	0.55 ± 0.03 **c**
	Titicaca	104.23 ± 1.52 **b**	2.64 ± 0.43 **b**
	Puno	65.73 ± 2.93 **c**	3.55 ± 0.21 **a**
	ICBA-Q4	72.93 ± 2.60 **c**	2.61 ± 0.25 **b**
	ICBA-Q5	53.13 ± 2.04 **d**	2.74 ± 0.18 **ab**
10.50	INIA 420-Negra	52.83 ± 1.49 **a**	0.33 ± 0.01 **d**
	Titicaca	33.37 ± 0.93 **c**	1.45 ± 0.18 **c**
	Puno	49.70 ± 3.00 **a**	1.83 ± 0.06 **b**
	ICBA-Q4	40.30 ± 0.31 **b**	1.78 ± 0.06 **b**
	ICBA-Q5	35.67 ± 1.62 **bc**	2.17 ± 0.05 **a**

In each column and for each salinity level (EC), values followed by the same letters are statistically homogeneous ($p \leq 0.05$).

3.2. Discussion

According to this study, the investigated parameters during the quinoa life cycle were significantly affected by water irrigation salinity at 10.5 $dS.m^{-1}$ that caused losses in yield and dry matter at harvest, respectively, of 66% and 52%. Previous results obtained by Razzaghi et al. (2012) supported the fact that increasing salinity leads to quinoa yield and biomass reduction [10]. However, Hirich et al. (2014) noted that the same cultivars, Puno, Titicaca, ICBA-Q4 and ICBA-Q5, cultivated in South Morocco were able to grow successfully above 10.5 $dS.m^{-1}$ and their grain yield and dry matter were not significantly affected up to 17 $dS.m^{-1}$ [11]. Nonetheless, our study indicates that this result depends on quinoa varieties' response to salt stress. In fact, ICBA-Q5 recorded the highest grain yield (2.17 $t.ha^{-1}$) with the minimum loss (21%) under salt stress, while INIA-420 NEGRA showed the lowest grain yield whatever the salinity level. This Peruvian long-life cycle variety should be sown early to avoid the effect of high temperature mainly during the flowering and grain filling stages.

According to Figure A1 and the late sowing date (March 13), these critical stages coincide with the period of maximum temperature, reaching 30 °C. Thus, managing the sowing date is also essential to reduce the negative effect of heat stress during the flowering and grain filling stages, and therefore the eventual losses of grain yield and biomass [12]. We will repeat this study in the following seasons in order to confirm these results.

Author Contributions: Conceptualization, I.A. and S.B.A.; methodology, I.A.; software, I.A. and F.G.; validation, S.B.A., D.B., A.H. and H.M.; formal analysis, I.A.; investigation, I.A.; resources, I.A. and S.B.A.; data curation, I.A.; writing—original draft preparation, I.A.; writing—review and editing, I.A. and S.B.A. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data collected from field measurements conducted on quinoa crops and soil and water analyses at the laboratory of the National Institute for Agronomic Research in Berkane.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

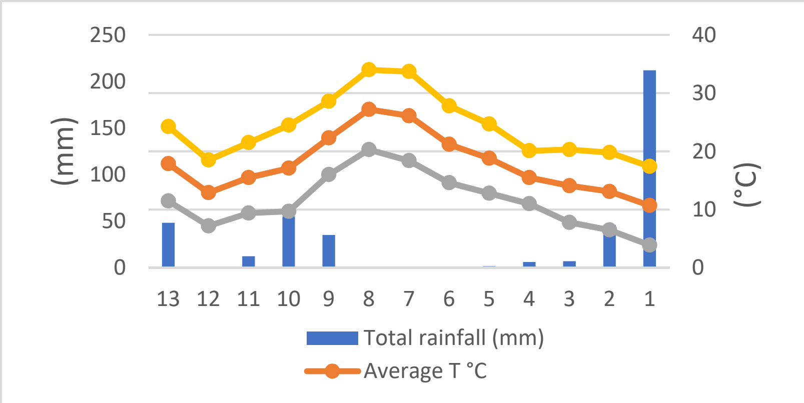

Figure A1. Climate parameters for the Berkane site (2020).

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