THE SALT TOLERANCE OF QUINOA MEASURED UNDER FIELD CONDITIONS

TOLERANCE DU QUINOA A LA SALINITÉ MESUREE AU CHAMP

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ABSTRACT

Plant growth and economic yield decreases when high salt concentrations build-up in the root zone. Quinoa is a facultative halophyte crop, which can withstand saline conditions. There is no documentation of the threshold soil electrical conductivity that cause yield reduction in quinoa under field conditions. In this study the threshold electrical conductivity of soil saturation extract (EC_e) and maximum EC_e corresponding to no economic yield of quinoa (cv. Titicaca) were determined. The experimental factors were five levels of saline solution (0, 10, 20, 30 and 40 dS m^{-1}) imposed during flowering stage followed by either full irrigation (FI) with tap water, or progressive drought (PD), during the seed filling period. The FI_0 yield was 2.45 t ha^{-1}, which was not significantly different from seed yield of PD_0. The maximum relative yield (with respect to the FI_0 treatment) was 97% obtained in PD_0 and the minimum relative yield was 47% observed at 40 dS m^{-1} saline solution (FI_{40}). The results showed that quinoa can grow under highly saline conditions although the seed yield decreases with increased EC_e. The threshold EC_e of quinoa was estimated to be between 3-6 dS m^{-1}. There was 50% reduction in seed yield of FI_{40} and PD_{40} treatments at EC_e of 24 dS m^{-1}. The EC_e leading to no economic seed yield was extrapolated to be 51.5 dS m^{-1}. The results showed that quinoa can be classified as a salt tolerant crop according to the Mass and Hoffman classification.

Key words: *Quinoa (chenopodium quinoa willd), salt tolerance, Lysimeter, Threshold electrical conductivity, relative yield.*

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RESUME ET CONCLUSIONS

La salinité est un problème majeur dans les régions arides et semi-arides. Elle est à l'origine d'une détérioration de la croissance des cultures et de la productivité. Le manque d'eau douce et l'augmentation de la population force à l'utilisation d'eau saline pour la production agricole. C'est pour cela qu'il est nécessaire d'introduire des cultures présentant une forte productivité dans des conditions salines. Les plantes halophytes ont développé des mécanismes physiologiques les rendant capables de tolérer des conditions salines. Ces mécanismes peuvent être grossièrement définis comme la tolérance à la salinité et l'évitement de la salinité. La tolérance à la salinité d'une culture peut être évaluée grâce à l'équation de Mass and Hoffman (1977) qui définie le seuil de salinité conduisant à une réduction des rendements économiques.

Le quinoa (Chenopodium quinoa willd.) est une plante halophyte capable de croître dans des conditions difficiles. Du quinoa (cv. Titicaca) a été semé dans des parcelles lysimétriques et irrigué avec de l'eau douce de façon à atteindre 95% de la capacité au champ jusqu'à la floraison. Après la floraison, l'irrigation se poursuivis pendant 18 jours, mais cette fois avec des solutions salines de différentes concentrations (0, 10, 20, 30 et 40 dS m-1). Puis, pendant 4 semaines de remplissage des graines, les parcelles ont été divisées en deux groupes : un groupe recevant de l'eau douce de façon à atteindre 95% de la capacité au champ (FI_0, FI_{10}, FI_{20}, FI_{30}, FI_{40}), et un groupe subissant un assèchement progressif (PD_0, PD_{10}, PD_{20}, PD_{30}, PD_{40}). Des échantillons de sol ont été prélevés tous les 10 cm dans la zone racinaire (0-60 cm) pour mesurer la teneur en eau pondérale et la salinité (conductivité électrique saturée, EC_e). Les rendements en graines ont été mesuré à la fin de la période de croissance (4 réplications).

Les objectifs de cette étude étaient de mettre en évidence les effets de la salinité sur la croissance du quinoa (cv. Titicaca) et de déterminer le seuil de tolérance à la salinité au-delà duquel une réduction des rendements en graines est significative et/ou les rendements économiques sont nuls.

Les rendements relatifs de quinoa ont diminués de 50 % pour une augmentation de l'EC_e de 0 à 24 dS m^{-1}. Les rendements relatifs en graines étaient maximum sans conditions salines suite à un assèchement (PD_0 : 97 %) et minimum dans le cas d'une irrigation avec une solution saline (FI_{40} : 47 %). Les rendements en graines de FI_0 étaient supérieurs à ceux de FI_{10} et PD_{10}, montrant que la salinité tolérable était située entre 3 et 6 dS m^{-1}. La conductivité électrique maximale, à laquelle les rendements économiques étaient nuls, était de 51.5 dS m^{-1}. Il est ainsi possible de cultiver le quinoa cv. Titicaca en conditions salines et de l'irriguer avec une solution aussi saline que l'eau de mer (40 dS m^{-1}). Le quinoa peut ainsi être qualifié de très tolérant à la salinité selon Tanji and Kielen, 2002.

Mots clés: *Quinoa (chenopodium quinoa willd), tolérance au sel, lysimètre, conductivité électrique maximale, rendement relatif.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Salinity is a major problem in arid and semi-arid regions especially with low amounts of fresh water, lack of precipitation and high evapotranspiration rate, which has a negative effect on crop production. Excess salinity in the root zone reduces plant growth and economic yield. However, saline water irrigation to salt tolerant crops is recommended in order to maintain sustainable levels of food production. Halophytes have physiological mechanisms to tolerate saline conditions. The salt tolerance of a crop can be described by plotting relative yield as a function of soil salinity (Mass and Hoffman, 1977). This plot can be used to determine the soil salinity levels that cause yield reduction.

Quinoa (Chenopodium quinoa Willd.) is a traditional and high nutritional food crop that has been cultivated in the Bolivian and Peruvian Andean region for around 7000 years (Garcia et al., 2007). It is well adapted to arid and semi-arid region and can grow from sea levels to high Andean mountains areas around 4000 m.a.sl. Apart from drought, quinoa is also adapted to frost and can grow in saline soil (Geerts et al., 2008; Jacobsen et al., 2003 a, b). However, there is still lack of information on threshold salinity levels of quinoa (*Chenopodium quinoa* Willd.) which is a facultative halophyte (Jacobsen and Mujica, 2003). The aim of this study was to investigate the levels of salinity that i) caused reduction in seed yield, ii) produced half yield, iii) no economic yield obtained and iv) further to determine whether quinoa is tolerant to salt.

2. MATERIALS AND METHODS

The Danish bred Quinoa (cv. Titicaca) was sown in 4.7 m^2 lysimeters. All plots were irrigated with tap water by a drip irrigation system to 95 % of field capacity until flowering stage. Irrigation was continued with different levels of saline solutions (0, 10, 20, 30 and 40 dS m^{-1}) for 18 days. Plots were divided between two levels of irrigation, full irrigation (FI; 95% of field capacity) and progressive drought (PD) treatments and denoted as FI_0, FI_{10}, FI_{20}, FI_{30}, FI_{40}; PD_0, PD_{10}, PD_{20}, PD_{30}, PD_{40}, arranged in a randomized, complete block design with four replicates. During soil drying, which continued for 4 weeks, the FI treatments were irrigated with tap water and then irrigation resumed with tap water for all treatments. Soil samples were taken from the root zone (0-60 cm, in 10 cm interval) during the irrigation period with saline solution and drought period from all plots. The soil samples were oven-dried at 105 ^oC for 24 hours to determine the gravimetric water content (θ_m). The volumetric water content (θ_v) for each depth interval was calculated using the soil bulk density (ρ_b) and θ_m of the corresponding depth. The saturated electrical conductivity (EC_e, dS m^{-1}) was calculated from measured electrical conductivity of soil water and θ_v. Seed yield was collected from four replications at the end of the growth period and it was dried at 85 ^oC for 24 hours to determine the dry seed weight.

To determine the threshold and maximum salinity level, the Mass and Hoffman (1977) equation was used:

$$Yr = 100 - b * (EC_e - a) \quad (1)$$

where *Yr* is relative yield, *b* is the slope expressed in percent yield decrease per unit increase of EC_e, (dS m^{-1}), EC_e is the mean saturated electrical conductivity of the root zone (dS m^{-1}) and *a* is the threshold salinity (dS m^{-1}) where yield starts to decrease.

3. RESULTS

Figure 1 shows the relative yield to FI_0 as a function of EC_e. There was no significant difference between the seed yield of FI_0 and PD_0. Seed yield of FI_0 (2.45 t ha-1; SE = ± 0.06; n = 4) was significantly higher than FI_{10} and PD_{10}, which had an EC_e of ca. 6 dS m^{-1}, demonstrating that the threshold ECe is between 3-6 dS m^{-1}. The maximum relative yield was observed in FI_0 and PD_0 and the minimum relative yield was in FI40 and PD40 with an ECe of ca. 24 dS m^{-1} resulting in ca. 50% reduction in seed yield. The regression equation shows that the extrapolated no economic yield level corresponded to a maximum EC_e of 51.5 dS m^{-1}. Therefore quinoa is highly tolerant to salinity when considering EC_e at 50 percent relative yield reduction (Figures 1 and 2).

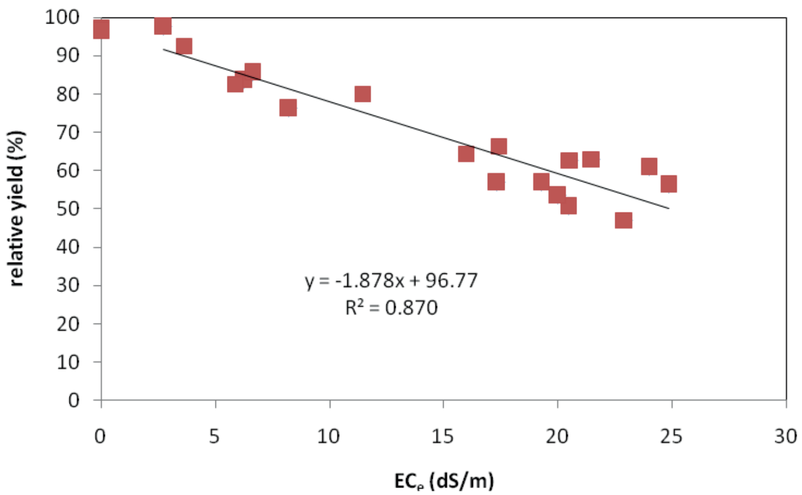

Fig. 1: Relationship between relative yield and EC_e (Relations entre les rendements relatifs et EC_e)

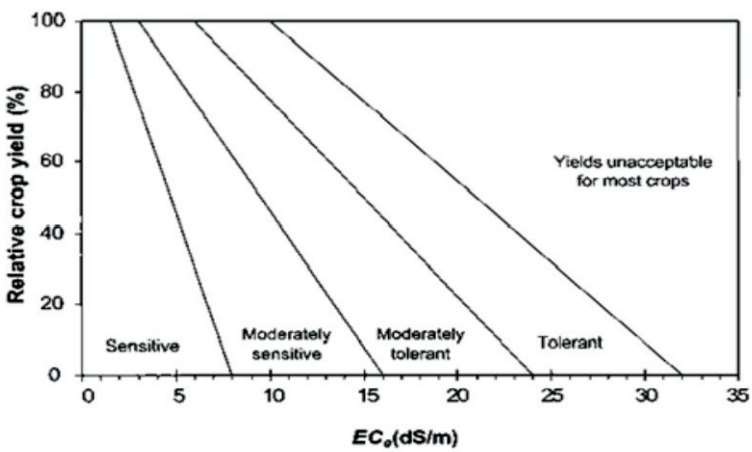

Fig. 2: Division of classifying crop tolerance to salinity (after Tanji and Kielen, 2002) (Classification de la tolerance des cultures à la salinité (d'après Tanji and Kielen, 2002))

Table 1 represents the salinity levels at which the 50 per cent reduction in yield occurs for different types of crops. According to Figure 1, a 50 per cent reduction in quinoa seed yield was obtained at EC_e of 24 dS m^{-1}, confirming the classification of quinoa (cv. Titicaca) as a high salt tolerant crop (Table 1).

Table 1: Division of salt tolerance crop according to USDA-Handbook 60 (Classification de la tolérance des cultures à la salinité d'après USDA-Handbook 60)

	Salinity for 50% yield decrease (ECe, dS m^{-1})		
	High tolerance	**Medium tolerance**	**Low tolerance**
Fruit crops	18	12	4
Forage crops	18	12	4
Field crops	16	10	4
Vegetable crops	12	10	2

4. CONCLUSIONS

This study showed that quinoa (cv. Titicaca) may be classified as a high salt tolerant crop able to produce yield under highly saline conditions.

REFERENCES

Garcia, M., Raes, D., Jacobsen, S-E., Michel, T., 2007. Agroclimatic contraints for rainfed agriculture in the Bolivian Altiplano. Journal of Arid Environments 71, 109–121.

Geerts, S., Garcia, M., Cusicanqui, J., Taboada, C., Miranda, R., Yucra, E., Raes, D. 2008. Review of current knowledge on Quinoa (Chenopodium quinoa Willd.). Editor: Faculty of Agronomy - Agronomic Engineering. Universidad Mayor de San Andres, Faculty of Agronomy - Agronomic Engineering. La Paz, Bolivia.29pp.

Jacobsen, S-E., Mujica, A., 2003. Quinoa: an alternative crop for saline soils. Journal of Experimental Botany 54, Suppl. 1, i25.

Jacobsen, S-E., Mujica, A., Jensen, C.R., 2003a. Resistance of quinoa (Chenopodium quinoa Willd.) to adverse abiotic factors. Journal of Experimental Botany 54, Suppl. 1, i21.

Jacobsen, S-E., Mujica, A., Jensen, C.R., 2003b. The resistance of quinoa (Chenopodium quinoa Willd.) to adverse abiotic factors. Food Reviews. International 19, 99–109.

Mass, E.V., Hoffmann, G.J. 1977. Crop salt tolerance-current assessment. ASCE J. Irrig. and Drainage Div. 103(IR2):115-134.

Tanji, K.K., Kielen, N.C. 2002. Agricultural drainage water management in arid and semi-arid areas. FAO Irrigation and Drainage Paper 61: 205 pp.

United States Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Editor Richards, L. A. U.S.D.A. Handbook 60.