International Journal of Science, Environment and Technology, Vol. 7, No 3, 2018, 997 – 1006

ISSN 2278-3687 (O)
2277-663X (P)

QUINOA AS A NEW CROP FOR SALTED LAND IN TUNISIA

Pr. Leila Radhouane
National Institute for Agricultural Research of Tunisia
Hédi Karray Street- 1004 El Menzeh- Tunisia
E-mail: Leila.radhouane@gmail.com

Abstract : Crop diversification is not an option, but a necessity to safeguard our food supplies, particularly in the context of climate change. Tunisia is among countries vulnerable to climate change and its agriculture is characterized by a high degree of risk due to a range of adverse climatic factors such as drought, and soil salinity.

The salt sensitivity of major food crops combined with gradual global climate change requires investigation of stress tolerant, alternative food crops such as atypical quinoa (*Chenopodium quinoa*). It draws attention with its high nutritional value and it is highly resistant to weather and soil conditions. In Tunisia, little information is known about quinoa crop characteristics under stress conditions. The aim of this work is to study its germination and its seedling characters at different level of salinity.

Seeds of quinoa were obtained from Morocco, but originating in Peru. After sterilization, 50 seeds were transferred into 9 cm Petri dishes containing filter paper. The saline treatments used were 0, 1, 3, 6, 9 g/l NaCl solutions. The Petri dishes were put in an incubator at 25°C in the dark. Seeds were considered to have germinated with the emergence of the radicle. The parameters studied were the rate of germination, germination velocity and coleoptile and radicle length.

The results revealed that the germination of C. *quinoa* seeds started early in distilled water. In NaCl, maximum germination occurred later than in control. The germination velocity decreased in response to the increase of salt concentration in the medium. For germination rate, results demonstrated that all seeds germinated in the control and both NaCl and was not affected by salinity. On the contrary, there is a significant germination rate improvement for medium containing 3g/l NaCl. In this concentration, quinoa had the longest coleoptile while the longest radicle was obtained under the level of 6 g/l NaCl. It may be concluded that quinoa proves a great capability of dealing with salinity in this early and critical phase of development and offer the possibility of being an alternative promising crop under salinities.

Keywords: Quinoa; salinity; germination; Tunisia; climate change; arid region.

Introduction

Plant genetic resources for agriculture play an increasingly role for food security and economic development worldwide. These resources, as integrated components of agricultural biodiversity are crucial for increasing agricultural production in a sustainable way and to ensure the livelihood of a large number of people dependent on agriculture. In fact, crop diversification is not an option, but a necessity to safeguard our food supplies. This

*Received May 17, 2018 * Published June 2, 2018 * www.ijset.net*

diversification becomes more significant under climate change which impacts on ecosystems and biodiversity are also likely to be devastating (Cox et al., 1998).

Tunisia is among countries vulnerable to climate change (Giorgi, 2006) and its agriculture is characterized by a high degree of risk due to a range of adverse climatic factors such as drought and soil salinity (Radhouane, 2013a).

Salinity is one of the most widespread environmental threats to global crop production, especially in arid and semi-arid climates (Chaves et al., 2003), where land degradation, water shortage and population growth are already a major concern (Geissler et al., 2010). Hence, the future of agricultural production will increasingly rely on our ability to grow plants on salt-affected and marginal lands using low (brackish or even saline) waters (Rozema and Flowers, 2008; Schmöckel et al., 2017). In this context, the success of germination stage is a crucial because the first imperative of a satisfactory culture consists of its suitable establishment and determines the entire period of vegetation. In fact, when establishment levels are low, higher seedling rates are required, yield is reduced and replanting may be necessary, all of which reduce financial returns (Radhouane, 2011). Furthermore, the answer of seeds to salinity could also be an indicator of the tolerance of plants for the later stages of development. The tolerance of many species to salinity during germination stage constitutes an advantage because it leads to the establishment of these species in zones where others, sensitive to salinity, cannot colonize, and permit the fast occupation of the space (Radhouane, 2007).

The salt sensitivity of major food crops combined with gradual global climate change requires investigation of stress tolerant, alternative food crops such as atypical quinoa (*Chenopodium quinoa*).

Quinoa's tolerance to abiotic stresses is one of the reasons why the FAO declared 2013 as the International Year of Quinoa and to promote it as one of the crops that alleviate world hunger and poverty (Bazile et al., 2015**).**

It draws attention with its high nutritional value (Repo-Carrasco et al., 2003; Bhargava et al., 2006; Nauta et al., 2013) and more importantly, it is highly resistant to climate, soil conditions (Geerts et al., 2006; González et al., 2009; Coulibaly, 2013) and salinity (Hariadi et al., 2011; Razzaghi et al., 2012; Adolf et al., 2012; Rozema et al., 2015; Gordillo-Bastidas et al., 2016).

Several results also showed that Quinoa possess genetic mechanisms that are triggered in response to salinity (Orsini et al. 2011; Ruiz-Carrasco et al. 2011).

In Tunisia, little information is known about quinoa crop characteristics under abiotic stresses. The efforts focused on evaluation of the seeds collected for their adaptation to the arid and semi-arid regions, particularly under salinity.

The aim of this work is to study the germination and the seedling characters at different level of salinity in quinoa seeds in the objective to test if quinoa could replace the wheat crop in areas from which it has already disappeared due to the degraded conditions.

Material and methods

Seeds of C. quinoa Willd. were obtained from Morocco, but originating in Peru. After sterilization, 50 seeds were transferred into sterilized 9 cm Petri dishes containing filter paper and soaked by 5 ml of the saline treatments compared to a control treated with distilled water. Saline treatments used were 1, 3, 6, 9 g/l NaCl solutions. The Petri dishes were put in an incubator at 25°C. Seeds were considered to have germinated when the radicle had extended at least 2 mm. The number of seeds germinated was recorded daily for up to 7 days. The parameters studied to characterize the salt tolerance were germination percentage, germination velocity coefficient (Kader and Jutzi 2004) and hypocotyl and radicle length (Radhouane, 2011).

Data were analyzed with analysis of variance (ANOVA) and means were separated by the least significant difference (L.S.D.) using $P < 0.05$.

Results and discussion

Seed germination is a key factor in the life of a plant, especially in the presence of some limiting factors. The study of the influence of salinity on seedling characters using several salt concentrations is one of the methods in the study of resistance during the germinal phase. This investigation monitored changes caused by salt stress in germination rate and velocity and coleoptile and radicle lengths of *Chenopodium quinoa* Willd. seeds.

1. Effect of salinity on germination

For germination percentage, results demonstrated that all quinoa seeds (100%) germinated in the control and both NaCl and was not affected by salinity (Table 1). Similar results were found by Ruiz-Carrasco et al. (2011) and Panuccio et al. (2014).

Gonzalez and Prado (1992) and Ruiz-Carrasco et al. (2011) found that germination percentages did not differ significantly between 0 and 200 mM NaCl treated seeds. They demonstrated that under 200 mM NaCl, germination decreased only for some quinoa genotypes. The capability of germination and seedling establishment under saline conditions is dependent on cultivar and probably also on the substrate in which the seeds germinate

(Bendevis et al., 2013). However, quinoa proves in general a great capability of dealing with salinity in this early and critical phase of development.

The results revealed also that the germination of C. *quinoa* seeds started early in distilled water and reached the maximum in 10~15 h. In NaCl, maximum germination occured later than in control. However, salinity solution of 3g/l NaCl improved germination velocity but not significantly relative to control.

Brakez et al. (2014) found that germination percentage reached its maximum in the 3th day after sowing and there was no significant difference between control and 50 mM NaCl. They established that above this concentration, germination velocity decreased significantly.

In others studies, Prado et al. (2000) demonstrated that salt concentration of 0.1 M delayed germination slightly, and higher concentrations caused progressively strong inhibition, with maximum effect resulting at 0.4 M.

Quinoa plants responded to salinity treatment in a manner typical of halophytes. Its tolerance to salinity was attributed to several traits well orchestrated, forming several "lines of defence" in mesophyll cells. In fact, Koyro and Eisa (2008) and Adolph et al. (2013) had found that quinoa had a highly protected seed interior. Several researchers (Hariadi et al., 2011) suggested that seed viability was dependent on its ability to exclude toxic Na^+ from the developing embryo in order to avoid ion toxicity. Shabala and Cuin (2008) and Bonales-Alatorre et al. (2013) advanced that quinoa had much a better ability to retain K^+ in the leaf mesophyll. Quinoa's high salinity tolerance is attributed to tight control of ion homeostasis either by excluding Na^+ from the shoot, using it for osmotic adjustment, or by sequestering it into the vacuole (Adolf et al., 2013).

In ulterior study, Ungar (1996) suggested that quinoa seeds may develop an osmotically enforced "dormancy" in the presence of NaCl, which is removed once that seeds are transferred to distilled water.

Table 1. Germination percentage and germination velocity of quinoa seeds after 7 days of growth under different salinity levels

NaCl (g/l)	Germination (%)	Germination velocity (%)
0	100	35 a
1	100	37 a
3	100	39 a
6	100	30 b
9	100	25 c

2. Effect of salinity on coleoptile and radicle length

Moderate salinity level (3g/l NaCl) led to 22 and 66% increase, respectively, in the plant coleoptile and radicle lengths, relative to control. Under this salt concentration, the shoot length of seedlings decreased with an increase in water salinity (Table 2). In contrast, root elongation increased with an increase of salinity. Salt level of 9g/l NaCl improved root length by 111% but decreased shoot length by about 30%.

Moderate salinity level (3g/l NaCl) had improved coleoptile length of quinoa ecotype that reached longest size in this concentration and then decreased with increasing salinity. Similar result is corroborate by Jacobsen et al. (2003) and Gomez-Pando et al. (2010).

This result also joined those of Brakez et al. (2012) on quinoa and other species like *Glycine soja* (Li, 2008) and *Pennisetum glaucum* (Radhouane, 2008). Others authors had indicated that low salt treatment plants was more beneficial than no added salt (Maughan et al., 2009).

Salinity higher than 3g/l NaCl reduced shoot length but increased radicle length. In this context, Ruiz-Carrasco et al.(2011) had also found that salinity of 150 mM NaCl induced a slight (approximately 20%) reduction of shoot length relative to untreated controls for some Chilean quinoa accessions. Hariadi et al. (2011) were demonstrated that germination and seedling root and shoot length were scarcely affected or unaffected by application of 150 mM NaCl, or even enhanced (root length), confirming the halophytic nature of quinoa.

Increasing root length under salt stress may reflect an adaptive response involving to reach deeper water in the soil (Radhouane, 2007) and can be used as useful traits to screen germplasm collections for salt tolerance in many species (Munns an Tester, 2007).

Growth stimulation under moderate salinities has been reported previously for *C. quinoa* (Gómez-Pando et al. , 2010; Shabala et al., 2013; Turcios et al., 2016) and many other halophytic species (Morales et al., 2012; Radhouane, 2013b). This positive response to moderate salinities might be largely the consequence of increased tissue water content (Liu et al., 2002; Khan et al., 2005). Slower growth is a general adaptive feature for plant survival under stress, allowing re-directing cell resources (e.g., energy and metabolic precursors) towards the defence reactions against stress (Zhu, 2001; Radhouane, 2013). Maintenance of favorable plant water status contributes to salinity tolerance of the salt tolerant ecotypes (Oweis, 2009).

Based on this behaviour under moderate salinity and on previous studies regarding some physiological parameters related to salinity adaptation in a quinoa cultivars (Koyro et al., 2008; Maughan et al., 2009; Orsini et al., 2011; Hariadi et al., 2011; Yazar et al., 2015; Choukrallah et al., 2016) the specie may be described as a facultative halophyte.

Table 2. Coleoptile and radicle lengths after 7 days of growth under different salinity levels

Salinity level NaCL (g/l)	CL (cm)	RL (cm)
0	4.5c	0.9c
1	4.8b	1.3b
3	5.5a	1.5b
6	3.2d	2.0a
9	3.1d	1.9a

CL: coleoptile length, RL: radicle length

Conclusion

In the Mediterranean region where water is scarse and generally saline, utilisation of halophytes as crops would help in highly salinized zones. Quinoa had proved a great capability of dealing with salinity.

Quinoa used in this study is enabling to be a widely distributed on all saline zones especially near the sea to help the poor agricultural economy of semiarid regions of the Mediterranean area. Quinoa may be utilized for different applied purposes: production of biomass for energy, enzymes or antioxidants and phytorremediation programs of saline soils.

References

[1] Adolf, V.I.; Jacobsen, S.E.; Shabala, S.; 2013. Salt tolerance mechanisms in quinoa (*Chenopodium quinoa*). Env. Exp. Bot., 92: 43- 54.

[2] Bendevis, M.A.; Sun, Y.; Shabala, S.; Rosenqvist, E.; Liu, F.; Jacobsen, S.E.; 2013. Photoperiod dependent ABA and soluble sugar responses of quinoa. Annals of Botany, 104: 925-936.

[3] Bhargava, A.; Shukla, S.; Ohri D.; 2006. *Chenopodium quinoa*: an Indian perspective. Ind. Crops Prod., 23: 73- 87.

[4] Bonales-Alatorre, E.; Pottosin, I.; Shabala, L.; Chen, Z.H.; Zeng, F.; Jacobsen, S.E.; Shabala, S.; 2013. Differential Activity of Plasma and Vacuolar Membrane Transporters Contributes to Genotypic Differences in Salinity Tolerance in a Halophyte Species, *Chenopodium quinoa.* Int. J. Mol. Sci., 14: 9267-9285.

[5] Brakez, M.; Harrouni, M.C.; Tachbibi, N.; Daoud, S.; 2014. Comparative effect of NaCl and seawater on germination of quinoa seed (*Chenopodium quinoa* willd). Emir. J. Food Agric., 26 (12): 1091-1096

[6] Chaves, M.M.; Maroco, J.P.; Pereira, J.S.; 2003. Understanding plant responses to drought-from genes to the whole plant. Funct. Plant Biol., 30: 239-264

[7] Choukr-Allah, R.; Rao, N.K.; Hirich, A.; Shahid, M.; Alshankiti,A.; Toderich, K.; Gill, S.; Butt, K.U.; 2016. Quinoa for Marginal Environments: Toward Future Food and Nutritional Security in MENA and Central Asia Regions. Frontiers in Plant Science, 7: 1-11.

[8] Coulibaly, A.K.; Sangare, A.; Konate, M.; Traore, S.; Ruiz, K.B.; Martínez, E.A.; Zurita, A.R.; Antognoni, F.; Biondi, S.; Maldonado, S.; León, P.; Bazile, D.; 2013. Evaluación de quinoa (*Chenopodium quinoa* Willd.) y adaptación a las condiciones agroclimáticas de Mali África oeste: un ejemplo de colaboración sur-norte-sur. *In* FAO. *Estado del arte de la quinua en el mundo*. Rome.

[9] Cox, P.M.; Huntingford, C.; Harding, R.J.; 1998. A canopy conductance and photosynthesis model for use in a GCM land surface scheme. J. Hydrol., 213: 79-94.

[10] Geerts S. et al.; 2006. Agro-climatic suitability mapping for crop production in the Bolivian Altiplano: A case study for quinoa. Agric. Forest Meteorol., 139: 399- 412

[11] Geissler, N.; Hussin, S.; Koyro, H.W.; 2010. Elevated atmospheric CO_2 concentration enhances salinity tolerance in Aster *tripolium* L. Planta, 231: 583–594

[12] Giorgi, F.; 2006. Climate change hot-spots. Geophysical Resources Letters, 33: 707-715.

[13] Gómez-Pando, L.R.; Álvarez-Castro, R.; de la Barra, E.; 2010. Effect of salt stress on Peruvian germplasm of *Chenopodium quinoa* Willd.: a promising crop. Journal of Agronomy and Crop Science, 196: 391-396.

[14] Gonzalez, J.A. and Prado, F.E.; 1992. Germination in relation to salinity and temperature in *Chenopodium quinoa* (Willd.). Agrochimica (Italy) 36 (1–2): 101–110.

[15] González, J.A.; Gallardo, M.; Hilal, M.; Rosa, M.; Prado, F.E.; 2009. Physiological responses of quinoa (Chenopodium quinoa Willd.) to drought and waterlogging stresses: dry matter partitioning. Botanical Studies, 50: 35-42.

[16] Gordillo-Bastidas, E.; Díaz-Rizzolo, D. A.; Roura, E.; Massanés, T.; Gomis, R. ; 2016. Quinoa (Chenopodium quinoa Willd), from nutritional value to potential health benefits: an integrative review. J. Nutr. Food Sci., 6: 497.

[17] Hariadi, Y.; Marandon, K.; Tian, Y.; Jacobsen S. E.; Shabala S.; 2011. Ionic and osmotic relations in quinoa (*Chenopodium quinoa* Willd.) plants grown at various salinity levels. J. Exp. Bot., 62: 185–193.

[18] Jacobsen, S. E.; Mujica, A.; Jensen, C. R.; 2003. The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. Food Rev. Int. 19: 99-109.

[19] Kader, M.A. and Jutzi, S.C.; 2004. Effects of thermal and salt treatments during imbibition on germination and seedling growth of sorghum at 42/19 8C. Journal of Agronomy and Crop Science, 190: 35–38.

[20] Khan, M.A.; Ungar, I.A.; Showalter, A.M.; 2005. Salt stimulation and tolerance in an intertidal stem-succulent halophyte. J.Plant Nutr., 28:1365–374

[21] Koyro, H.W. and Eisa, S.S.; 2008. Effect of salinity on composition, viability and germination of seeds of Chenopodium quinoa Willd, Plant Soil, 302: 79-90.

[22] Li, Y.; 2008. Effect of Salt Stress on Seed Germination and Seedling Growth of Three Salinity Plants. Pak. J. Biol. Sci., 11:1268- 1272

[23] Liu, F. and Stützel, H.; 2002. Leaf expansion, stomatal conductance and transpiration of vegetable amaranth (*Amaranthus* spp.) in response to soil drying. J. Am. Soc. Hort. Sci., 127: 878-883.

[24] Maughan, P.J.; Turner, T.B.; Coleman, C.E.; Elzinga, D.B.; Jellen, E.N.;. Morales, J.A.; Udall, J.A.; Fairbanks, D.J.; Bonifacio, A.; 2009. Characterization of Salt Overly Sensitive 1(SOS1) gene homoeologs in quinoa (Chenopodium quinoa Willd, Genome, 52: 1-11.

[25] Morales, A.J.; Bajgain, P.; Garver, Z.; Peter, J.; Maughan, P.J.; Udall, J.A.; 2012. Physiological responses of Chenopodium quinoa to salt stress. Int. J. Plant Physiol. Biochem. 3: 219–232

[26] Munns, R. and Tester, M. 2008. Mechanisms of salinity tolerance, Annu. Rev. Plant Biol. 59: 651- 681.

[27] Nauta, A.J.; Ben Amor, K.; Knol, J.; Garssen, J.; van der Beek, E.; 2013. Relevance of pre- and postnatal nutrition to development and interplay between the microbiota and metabolic and immune systems. The American Journal of Clinical Nutrition, 98: 586-593

[28] Orsini, F. ; Accorsi, M. ; Gianquinto, G. ; Dinelli, G. ; Antognoni, F. ; Ruiz-Carrasco, K.B. ; Martinez, E.A. ; Alnayef, M. ; Marotti, I. ; Bosi, S. ; Biondi, S.; 2011. Beyond the ionic and osmotic response to salinity in Chenopodium quinoa: functional elements of successful halophytism. Funct. Plant Biol. 38: 818- 831.

[29] Oweis, M. 2009. Durum wheat and barley productivity in saline–drought environments. Europ. J. Agr. 31(1): 1-9.

[30] Panuccio, M.R.; Jacobsen, S.E.; Akhtar, S.S.; Muscolo, A.; 2014. Effect of saline water on seed germination and early seedling growth of the halophyte quinoa in Physiology and Ecology of Halophytes—Plants Living in Salt-Rich Environments. AoB Plants, Special issue: 1-18.

[31] Prado, F.E.; Boero, C.; Gallardo, M.; Gonzalez, J.A.; 2000. Effect of NaCl on germination, growth, and soluble sugar content in Chenopodium quinoa Willd. seeds. Botanical Bulletin of Academia Sinica, 41: 27–34.

[32] Radhouane, L.; 2007. Response of Tunisian autochthonous pearl millet (Pennisetum glaucum (L.) R. Br.) to drought stress induced by polyethylene glycol (PEG) 6000. African Journal of Biotechnology, 6 (9): 1102-1105.

[33] Radhouane, L.; 2008. Effet du stress salin sur la germination, la croissance et la production en grains chez quelques écotypes de mil (*Pennisetum glaucum L. R. Br.)* autochtones de Tunisie. Comptes Rendus Biologies, 331(4): 278- 286.

[34] Radhouane, L.; 2011. Seedling characters at different temperatures in pearl millet (*Pennisetum glaucum* (L.) R. Br.). African Journal of Biotechnology, 10(55): 11421-11425.

[35] Radhouane, L.; 2013a. Climate change impacts on North African countries and on some Tunisian economic sectors. Journal of Agriculture and Environment for International Development (JAEID) 107 (1): 101-113.

[36] Radhouane, L.; 2013b. Agronomic and physiological responses of pearl millet ecotype (*Pennisetum glaucum* (L.) R. Br.) to saline irrigation. Emir. J. Food Agric., 25 (2): 109-116.

[37] Razzaghi, F.; Plauborg, F.; Jacobsen, S.E.; Jensen, C.R.; Andersen, M.N.; 2012. Effect of nitrogen and water availability of three soil types on yield, radiation use efficiency and evapotranspiration in field-grown quinoa. Agricultural water management, 109: 20-29.

[38] Repo-Carrasco, R.; Espinoza, C.; Jacobsen, S.E.; 2003. Nutritional value and use of the Andean crops quinoa *(Chenopodium quinoa)* and kaniwa *(Chenopodium pallidicaule).* Food Reviews International, 19: 179-189.

[39] Rozema, J. and Flowers, T.; 2008. Crops for a salinized world. Science, 322: 1478–1480.

[40] Rozema, J.; Cornelisse, D. ; Zhang, Y. ; Li, H. ; Bruning, B. ; Katschnig, D. Broekman, R.; Ji, B.; van Bodegom, P.; 2015. Comparing salt tolerance of beet cultivars and their halophytic ancestor: consequences of domestication and breeding programmes. AoB Plants 7: plu083. doi: 10.1093/aobpla/plu083.

[41] Ruiz-Carrasco, K.; Antognoni, F.; Coulibaly, A.K.; Lizardi, S.; Covarrubias, A.; Martínez, E.A.; Molina-Montenegro, M.A.; Biondi, S.; Zurita-Silva, A.; 2011. Variation in salinity tolerance of four lowland genotypes of quinoa (*Chenopodium quinoa Willd*.) as assessed by growth, physiological traits, and sodium transporter gene expression. Plant Physiology and Biochemistry, 49: 133-1341.

[42] Shabala, S., and Cuin, T. A.; 2008. Potassium transport and plant salt tolerance. Physiol. Plant 133, 651–669.

[43] Shabala, S.; Hariadi,Y.; Jacobsen, S.E.; 2013. Genotypic difference in salinity tolerance in quinoa is determined by differential control of xylem Na^+ loading and stomatal density. J. Plant Physiol., 170: 906–14.

[44] Schmöckel, S.M.; Lightfoot, D.J.; Razali, R.; Tester, M.; Jarvis, D.E.; 2017. Identification of Putative Transmembrane Proteins Involved in Salinity Tolerance in Chenopodium quinoa by Integrating Physiological Data, RNAseq, and SNP Analyses. Front. Plant Sci., 8 (1023): 1-12

[45] Turcios, A. E.; Weichgrebe, D.; Papenbrock, J.; 2016. Potential use of the facultative halophyte Chenopodium quinoa Willd. as substrate for biogas production cultivated with different concentrations of sodium chloride under hydroponic conditions. Bioresource Technology, 203: 272–279

[46] Ungar, I.A. 1996. Effect of salinity on seed germination, growth and ion accumulation of Atriplex patula (Chenopodiaceae). Amer. J.Bot., 83: 604-607.

[47] Yazar, A.; Incekaya, C.; Sezen, M.; Jacobsen, S.E.; 2015. Saline water irrigation of quinoa (*Chenopodium quinoa*) under Mediterranean conditions. Crop & Pasture Science, http://dx.doi.org/10.1071/CP14243

[48] Zhu, J. K.; 2001. Plant salt tolerance. Trends Plant Sci. 6: 66-72.