

The Effect of Drought on Water Regime and Growth of Quinoa (*Chenopodium quinoa* Willd.)

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Summary: Quinoa (*Chenopodium quinoa* Willd.) is a highly nutritious Andean seed crop which shows great potential to grow under a range of different stress environments. The objective of this study was to investigate the effect of drought on water regime and the growth of quinoa variety KVL52 in controlled conditions. The results of the present experiment indicate that the reaction of quinoa plants to drought are based on drought avoidance mechanisms: reduced transpiration and sustained water uptake. Transpiration was reduced due to the decrease of stomatal conductance and leaf area development. These results could be of practical importance for testing the possibility of growing quinoa as a new drought resistant crop in Serbia.

Keywords: *Chenopodium quinoa*, drought, plant growth, quinoa, water regime

Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a seed crop of the *Chenopodiaceae* family, traditionally cultivated in the Andean region for several thousand years. Quinoa is considered as a multipurpose agricultural crop. The seeds may be utilized for human food, in flour products and in animal feedstock because of its high nutritive value (Jacobsen 2003). As a result of quinoa nutritional qualities, the global interest in quinoa is rapidly increasing. High nutritional value of quinoa seeds is mainly due to the high protein content and essential fatty acids as well as a wide range of minerals and vitamins (Stikić et al. 2012). Special attention has been given to quinoa for people with celiac disease (allergy to gluten), as an alternative to the cereals wheat, rye and barley (Jacobsen 2003). Additionally, quinoa seeds contain high levels of polyphenols and flavonoids, which are beneficial for human health (Repo-Carrasco-Valencia et al. 2010).

Worldwide results also confirm quinoa's potential for growing as an alternative crop in the regions where drought, high temperature, salt stress conditions or poor soil quality are the major constraints on efficient agricultural productivity (Jacobsen et al. 2003, Razzaghi et al. 2012, Cocozza et al. 2013). However, soil moisture plays an important role in determining the time and rate

of quinoa seed germination and seedling growth (Gonzalez et al. 2009). Due to its significant nutrient values and ability to grown in different agro-ecological conditions, quinoa has been selected by FAO as one of the crops destined to offer food security in the 21st century (FAO 2013).

Nevertheless, studies of the quinoa plant's ability to survive drought and other stress conditions are scarce. The aim of the present study was to assess the effect of drought on water regime and the growth of quinoa plants grown in controlled environmental conditions. This information could be of practical importance for testing the possibility of growing quinoa as a new drought resistant crop in Serbia.

Material and Methods

For this study, we used quinoa (*Chenopodium quinoa* Willd.) variety KVL52 provided by the University of Copenhagen. KVL52 has been registered as a new quinoa variety in Europe and selected for adaptation to European climatic conditions.

Quinoa was raised from seed and transplanted into pots (one plant per pot) filled with commercial compost (Klasmann Potground H). Plants were grown in a growth chamber (photoperiod was 14^h; light intensity at plant level 300 $\mu\text{molm}^{-2}\text{s}^{-1}$, temperature 25/18°C and relative humidity 60%).

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Plants were irrigated daily to full pot holding capacity, volumetric soil water content (θ) of 36%. In the phase of bud formation drought treatment was applied by withholding irrigation from pots and the treatment lasted 12 days. The θ was measured using a Theta probe (ML2x, Delta-T Device) and plant water potential by pressure chamber (Soil Moisture Equipment Corp., Santa Barbara, CA, USA). Stomatal conductance was measured by porometer (SC-1 leaf porometer, Decagon Devices, Inc.). Plant growth was characterized by plant height, leaf area and plant biomass and measured at the end of the experiment. Leaf area was determined destructively by sampling leaves from plants and measured by area meter (LI-COR). Leaf, stem and root samples were collected and their dry weights were measured at the end of the experiment. Data were analysed using analysis of variance (ANOVA, STAT), and treatment means were compared with Student's t-test using (Sigma Plot 6.0 for Windows - SPW 6.0, Jandel Scientific, Erckhart, Germany).

Results and Discussion

Results of the measured parameters of soil water content and quinoa leaves, water regime parameters are presented in Figures 1, 2 and 3. During drought treatment (D) soil water content decreased from 36.33 to 9.15 %, while the soil water content in full irrigation treatment (FI, control) was maintained at the level of *ca.* 35% (Fig. 1). These results indicated that plants were exposed to significant water deficiency.

Plant water regime in optimal (control) and drought conditions was characterized on the base of

water potential and stomatal conductance measurements. These results showed that the values of the water potential dropped from the -0.6 MPa at the beginning of drought to about -1.6 MPa at the end of drought treatment. In FI conditions, the water potential values varied from -0.6 MPa to -0.8 MPa (Fig. 2). Leaf water potential changes in both treatments were closely related to soil water content.

Stomatal conductance measurements (Fig. 3) also showed a significant decrease in plants exposed to drought comparable to FI conditions. The values in drought conditions varied from 300 mmol/mm²/s (at the beginning of drought treatment) to *ca.* 90 mmol/mm²/s (day 12). At the same time the stomatal conductance in FI conditions did not change so much (from *ca.* 300 to 230).

It is well-known that drought stress is characterised by reduction of soil water content, diminished leaf water potential and turgor loss, stomatal closure and decreased rate of cell enlargement and growth. However, the magnitude of these changes and their consequences for plant metabolism and growth depends on the degree of stress. A comparison of our results with the values obtained by Sun et al. (2014) in similar experimental systems showed that their plants (quinoa hybrid Titicaca and variety Achachino) were exposed to a higher degree of stress. In both Titicaca and Achachino the water potential values declined to *ca.* -2.0 MPa (day 5) and *ca.* 50 mmol/mm²/s (Sun et al. 2014). Similar water regime results were also obtained when the same quinoa cultivars were exposed in other experiments to drought and salinity stress (Razzaghi et al. 2012).

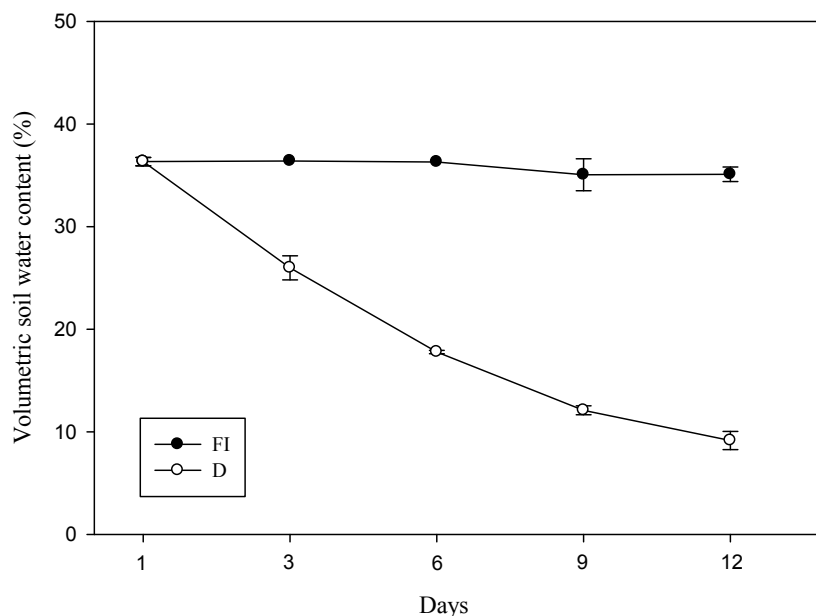


Figure 1. Changes in volumetric soil water content for full irrigation and drought

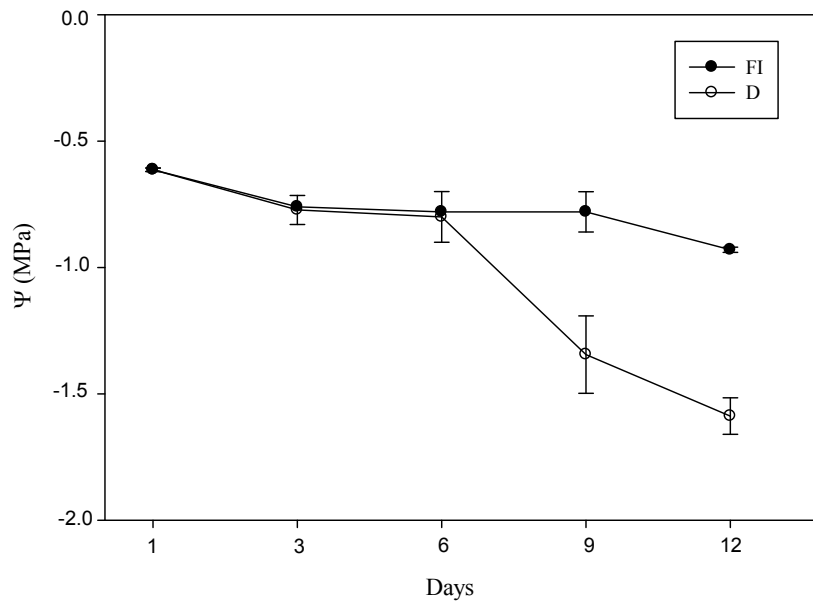


Figure 2. The effect of drought and full irrigation on water potential in the leaves of quinoa

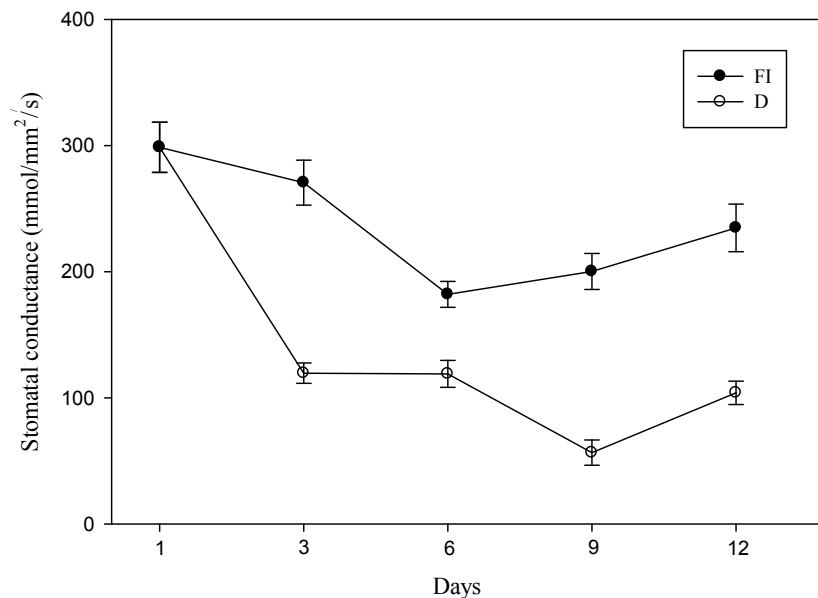


Figure 3. The effect of drought and full irrigation on stomatal conductance in the leaves of quinoa

Temporal measurements of plant water regime parameters also showed that stomatal response to drought was faster and more sensitive than water potential (Fig. 2 and 3). A decline in stomatal conductance was observed on the 3rd day on drought, while a drop in water potential was 3 days later (Fig. 2 and 3). After initiation of stomatal closure induced by drought, leaf water status was maintained for a more prolonged period. The threshold value when stomatal conductance starts to decrease was below -0.8 MPa. This is in agreement with the study of Jacobsen et al. (2009), but not with

the results of Jensen et al. (2000) who, under field conditions found stomatal closure in quinoa when the leaf water potential fell below -1.2 to -1.6 MPa.

Measurements of plant growth parameters included plant height, leaf area and plant biomass (Table 1). These results showed that plant height was not significantly affected by drought stress, while the total leaf area was significantly reduced (by 15%). Similarly, the reduction of biomass was also found for leaf and stem, by 18% each. However, the root biomass did not change significantly under drought conditions.

Table 1. Plant height, leaf area, leaf, stem and root dry weight of quinoa plants exposed to full irrigation and drought stress. Data are means for at least five measurements

Traits	Full irrigation (FI)	Drought (D)
Plant height (cm)	67.5	64
Leaf area (cm ²)	1511.56	1289.12*
DW leaf (g)	8.03	6.62*
DW stem (g)	3.09	2.54*
DW root (g)	1.27	1.23

(* indicates difference between FI and drought samples significant at $P < 0.05$)

Decrease in leaf area or leaf and stem biomass are often induced by drought in many crops, including quinoa. The inhibition of plant growth (plant height, leaf area and shoot biomass accumulation) in Sun et al. (2014) experimental system was greater than those measured in our experimental system. These results also confirmed that the sensitivity to drought of investigating quinoa cultivars Titicaca and Achachino in the experiment of Sun et al. (2014) was bigger comparing to our cultivar KVL 52. However, the results of Gonzales et al. (2009) showed smaller changes of biomass partitioning between organs of quinoa cultivar Sajama exposed to drought.

Our results also showed similarities between root biomass in drought and optimal water regime conditions (Table 1). Further investigation should be carried out to confirm if this similarity results of drought induced by re-allocation of biomass from shoots towards the roots. Such reactions of biomass partitioning have been reported as a response of many plants to drought stress (Munns 2002).

Quinoa's advantage is a vigorous, deep-rooting system. Due to the lack of seed dormancy, seedling emergence, including root elongations occurs quickly in the presence of adequate soil moisture. The deep branching root system allows water uptake even in drought conditions and significantly contributes to the high degree of drought resistance of this crop (Jacobsen & Stolen 1993).

The degree of plant growth or water regime changes depends on the plant's sensitivity or resistance to drought and could indicate their strategy to cope with drought. Drought avoidance mechanisms refer to the plant's ability to retain

relatively high level of hydration under water stress, and involve two components: maximizing water uptake and minimizing water loss. Maximizing water uptake can be achieved by increasing root growth, root thickness, root depth and mass. Water loss can be minimized by closing stomata, through reduced absorption of radiation by leaf rolling decreasing canopy area by reducing growth and shedding of older leaves (Jovanovic & Stikic 2012).

According to Munns et al. (2010) strategies for water use that confer drought tolerance can be quite different for dry land versus irrigated agriculture. According to these authors, the sensitive growth response to drought would be beneficial in rain-fed conditions, while the less sensitive response would be an advantage for crops growing in irrigated fields. However, drought resistance strategies are not mutually exclusive and plants may combine a range of different response types for optimal reaction to drought which were described for different quinoa cultivars (Razzaghi et al. 2012, Cocozza et al. 2013, Sun et al. 2014).

Conclusions

The results of our experiment indicate that the reaction of quinoa plants to drought is based on drought avoidance mechanism: reduced transpiration and sustained water uptake. Transpiration was reduced due to the decrease of stomatal conductance and leaf area development. Assimilate partitioning from shoots to roots allowed root growth and water uptake to continue even in drought conditions. However, more investigation about such drought response mechanism, especially in the field conditions, is required in the future.

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Efekat suše na vodni režim i rasteenje kvinoje (*Chenopodium quinoa* Willd.)

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Sažetak: Kvinoja (*Chenopodium quinoa* Willd.) je nutritivno visoko vredna kultura poreklom sa Anda, koja se može gajiti u različitim stresnim uslovima spoljašnje sredine. Cilj ovih istraživanja je bio da se ispita efekat suše na vodni režim i rasteenje sorte kvinoje KVL52 u kontrolisanim uslovima gajenja. Dobijeni rezultati ukazuju da su reakcije kvinoje na sušu bazirane na mehanizmu izbegavanja suše: redukciji transpiracije i održanju usvajanja vode. Transpiracija je redukovana zahvaljujući opadanju provodljivosti stoma i redukciji lisne površine. Ovi rezultati mogu biti od praktičnog značaja za testiranje mogućnosti gajenja kvinoje kao kulture koja je otporna na sušu i nova za gajenje u Srbiji.

Ključne reči: *Chenopodium quinoa*, kvinoja, rasteenje, suša, vodni režim