QUINOA: A POTENTIAL DROUGHT RESISTANT CROP FOR THE BRAZILIAN SAVANNAH

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Abstract

Quinoa (*Chenopodium quinoa* Willd.), a food crop of high quality protein and high in vitamins and minerals, has been grown in the Andean region for thousands of years. It has a pronounced resistance to the main adverse abiotic factors affecting crop production under the harsh conditions of the high Andes: drought, cold, and saline soils. All drought mediating mechanisms, including drought escape, drought tolerance and drought avoidance, are found in the species, although not all mechanisms are present in all genotypes. Quinoa escapes drought principally through early maturity, an important trait in areas where drought risk is likely toward the end of the growing season (terminal drought). Quinoa may tolerate drought through growth plasticity, low osmotic potential and tissue elasticity, and it may avoid drought through a deep, dense root system, reduction in leaf area by leaf dropping, by generating crystals of calcium oxalate, and through stomatal behaviour.

There is disagreement in the literature on the level of drought resistance actually attained by quinoa, and on the phenological phase of its susceptibility. Lund (1992) showed that seed production was reduced with less than 25% of field capacity in the soil, while Vasquez (1993) demonstrated that field capacity had to be decreased to 12.5% before seed yield was affected. Espíndola (1986) demonstrated that water deficiency during inflorescence formation and at flower initiation reduced seed yield by 40% and 65%, respectively. Different investigations show that the phases most drought susceptible with respect to grain production are vegetative, anthesis, and seed set. However, it has also been demonstrated that a certain level of drought in the vegetative phase may have a positive effect on the production of seed. Management practices, such as sowing time, row spacing and plant density, may also influence the water household of the crop. This divergence in results is understandable given the tremendous genetic variability in response to different ecotypes (valley, altiplano, salt desert, subtropics, and humid zones at sea level) reacting differently to a water deficit.

This paper presents recent findings on the mechanisms of drought resistance in quinoa, with emphasis on physiological responses such as leaf gas exchange and water relations.

Introduction

Subsistence agriculture in the Andean highlands is exposed to various adverse climatic factors such as drought, frost, wind and hail, high soil salt content, and soil erosion, all

of which complicate the agricultural development of the region. Furthermore, the high plateau of southern Peru and Bolivia, the altiplano, situated c. 4000 masl., experiences an atmospheric reduction of CO_2 pressure of 30-50% compared to sea level, resulting in a generally low crop productivity (Vacher et al., 1988; Morlon and Vacher, 1991).

Quinoa *(Chenopodium quinoa* Willd), a native South American plant species, is regarded as a crop with a high level of resistance to several of the predominant adverse factors. It has been cultivated in the Andean region for over 5000 years. Interest in quinoa has recently spread to Europe, where it has been demonstrated to have the potential to become a promising environmentally friendly newcomer requiring few or no inputs of pesticides and inorganic fertilizers (Risi and Galwey, 1991; Galwey, 1993; Jacobsen, 1997; Jacobsen and Stølen, 1993; Jacobsen et al., 1996).

The drought resistance of quinoa can be partly attributed to morphological characters, such as an extensive ramified root system and hygroscopic papillae on the leaf cuticula reducing transpiration (Canahua, 1977; Espindola, 1986), but data on the physiological response to drought are scarce. Andersen et al. (1996) concluded that quinoa has leaf water characteristics indicating drought resistance, including a low osmotic potential, low turgid weight/dry weight ratio, low elasticity, and an ability to maintain positive turgor even at low leaf water potentials. Rasmussen (1997) observed that quinoa quickly regains its former level of photosynthesis and specific leaf area after a period of severe drought, however, it was also shown that leaf conductance decreased in one genotype, with only a slight reduction in leaf water potential, while another cultivar maintained a high conductivity with a decreasing leaf water potential (Jacobsen, unpublished). García et al. (1991) showed, with two differing genotypes, that stomatal resistance is low even under drought, increasing moderately from 4-6 s cm^{-1} under irrigation to 8-9 s cm^{-1} under drought. Accordingly, under the same conditions, the resistance of potato increased from 10 to 200 s cm^{-1}. These observations indicate a generally low sensitivity to drought stress, but simultaneous varietal differences.

Potential evapotranspiration (ETP (Penman)), measured at the central altiplano of Bolivia, averaged 3.4 mm day^{-1}, with a maximum in December of 4.17 mm day^{-1} and a minimum in June of 2.39 mm day^{-1}, corresponding to variations in global sun radiation (Choquecallata et al., 1991). The k_c index relating maximal and potential evapotranspiration (ETM/ETP) of quinoa was highest at anthesis and seed set, close to or even above 1, and the seasonal average was 0.87, which places quinoa as a moderate water consumer. It was indicated that quinoa can be described as an adaptive crop, increasing the extraction of water even under a water deficit, without regulating transpiration (García et al., 1991).

The sensitivity to drought in various phenological phases, and the level of drought affecting seed and dry matter yield of quinoa, was demonstrated by Lund (1992). He showed that yield decreased significantly with a drying, but not before a soil water amount of 10-25% of field capacity was reached, less in seed set phase and during anthesis, and most deleteriously in vegetative phase. At 50% drying there was a tendency for a positive effect on yield.

The purpose of this study was to measure the effects of drought on leaf conductance, net photosynthesis, and leaf-water relations during drought at different stages of growth.

Materials and Methods

The experiment was conducted in 1997 as a pot experiment in the field at the experimental station Hoejbakkegaard of the Royal Veterinary and Agricultural University, situated 20 km west of Copenhagen, Denmark. The pots were 20 cm in diameter, and contained 21.6 kg loamy sand soil with a moisture content of 19 % at field capacity (pF=2) and 5 % at permanent wilting (pF=4.2). Two plants of quinoa (*Chenopodium quinoa* Willd**.** cv. Kankolla) were grown in each pot. Drought was imposed during branching, flowering, and grain filling stages of growth. Photosynthesis and conductance were measured with a LI-6200 portable photosynthesizer (LI-COR Inc. Lincoln, NE). Leaf water potential (Ψ_l) was measured in a pressure chamber, and leaf osmotic potential (Ψ_π) was determined with a psychrometer. Turgor pressure (Ψ_p) was calculated as $\Psi_p = \Psi_l - \Psi_\pi$. Relative water content (RWC) was determined by floating one half of the leaf on distilled water for 3 to 4 h at 22 °C under dim light. The turgid weight (TW) was then determined after blotting, and the dry weight was determined after the samples had been dried for 24 h at 80 °C. Fresh weight (FW), dry weight (DW) and turgid weight (TW) were used to determine the TW/DW ratio and RWC:

$$RWC = \frac{FW - DW}{TW - DW}.$$

Specific leaf area (SLA) was calculated as leaf area per unit of dry mass. The measurements were undertaken between 1200 and 1400 h.

Results

Considering only nonlimiting light conditions at an irradiance > 800 μmol m^{-2}s^{-1}, maximal net photosynthesis (A_{max}) of CO_2 under fully watered conditions in young, fully developed leaves was typically about 22 μmol m^{-2}s^{-1}. Leaf conductance (g_{H2O}) was 0.8 mol m^{-2}s^{-1} during branching, and 0.5 to 0.6 mol m^{-2}s^{-1} during flowering and grain filling. Stomatal closure occurred when leaf water potential (Ψ_l) was less than -0.9 to -1.1 MPa. The highest conductance was maintained at low leaf water potential during branching.

During soil drying, Ψ_l decreased from about -0.7 MPa to -2.4 in branching and flowering stages, and down to -3.2 MPa in seed set stage. Leaf osmotic potential (Ψ_π) decreased from -1.1 MPa to -2.7 MPa during branching, from -1.4 MPa to -2.7 MPa during flowering, and from -1.4 MPa to -3.5 MPa during grain filling. Turgor pressure (Ψ_p) was low but remained positive during the main part of the drying cycles. The osmotic potential at full turgor (Ψ_π x RWC) varied between -1.0 and -1.3 in fully watered plants. During drought the osmotic potential at full turgor decreased to -1.4 to -1.6 MPa indicating osmotic adjustment of about 0.3 MPa.

RWC was about 0.9 under fully watered conditions and fell below 0.65 during branching and flowering. During grain filling RWC decreased below 0.3. The TW/DW ratio decreased from 9 to 5 during branching. TW/DW was 4.7 during flowering and was 5-7 during grain filling. SLA was 22 during branching, 12-15 during flowering, and 16-21 during grain filling.

Discussion

The results indicate that the gas exchange parameters (g_{H2O} and A_{max}) of quinoa are within the normal range of C3-plants as compared with rape (Jensen et al., 1996), lupin (Jensen et al., 1989) and barley (Mogensen et al., 1994). However, osmotic potentials Ψ_π of quinoa were in the range of -1.0 to -1.3 MPa in fully hydrated plants, with a moderate osmotic adjustment of 0.3 MPa. That confirmed earlier findings (Andersen et al., 1996), where osmotic potentials at full turgor of -1.3 to -1.6 MPa were observed. Ψ_π was measured on expressed sap and may have to be adjusted for apoplastic water, because this fraction is about 16% in quinoa as estimated by the pressure-volume method (Andersen et al., 1996). The level of Ψ_π, found in quinoa, is comparable to that found in monocotyledonous species, e.g., in barley where Ψ_π at full hydration was also between -1.0 MPa and -1.3 MPa (Andersen et al., 1991). In other cultivated C3 dicotyledonuos plants such as lupin and rape, Ψ_π, values at full hydration were only -0.7 MPa and -0.9 MPa, respectively (Jensen and Henson, 1990; Jensen et al., 1996). The trait of a low osmotic potential in quinoa may be a mechanism of drought tolerance as reflected in turgor maintenance. However, the ability of osmotic adjustment of quinoa seems to be minor, both in the present experiment and in Andersen et al. (1996), not exceeding 0.4 MPa, neither could Delatorre et al. (1997) demonstrate a significant osmotic adjustment in quinoa.

The levels of leaf water potential obtained here were in accordance with the results of García et al. (1991), who showed that under irrigation predawn Ψ_l was from -0.5 to -1.0 MPa and in stressed conditions down to -1.5 MPa. The level of midday leaf water potential under irrigation was -1 to -2 MPa, and under drought -1.5 to -3 MPa. RWC remained almost constant under irrigation, with an average of 70%, decreasing to 50% under drought (García et al., 1991), which is less than has been observed in the present experiment.

We conclude that quinoa has gas exchange parameters (g_{H2O} and A_{max}) within the normal range of C3 plants, and the water relations are characterized by low osmotic potentials which may be an important part of quinoa´s drought tolerance.

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