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Water stress effects on growth, yield and quality traits of red beet

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ABSTRACT

The response of red beet to drought stress was investigated in order to explore the adaptive changes in plant growth, dry mass production and partitioning, yield, and accumulation of nutrients and bioactive molecules. Glasshouse experiments were conducted in 2012. Three water stress treatments were applied: (W100) 100% of water holding capacity (WHC), (W50) 50% of WHC, (W30) 30% of WHC. Water stress reduced storage root weight by 62% at W50 and 75% at W30 as well as leaf water content (LWC). With the progressive water stress, plant allocated less dry matter into roots leading to reductions of 32% and 43% in W50 and W30, respectively as compared to W100. Stomatal conductance was strongly reduced (from 496 to 211 mmol m^{-2} s^{-1} in W100 and W30, respectively); canopy temperature (CT) reflected the available water, with differences of 11 °C. Drought induced a significantly higher concentration of total phenolic content (a 86% increase) and betalains (52% and 70% increases in betacyanin and betaxanthin) and consequently, a higher antioxidant activity was obtained. Minerals such as Mg, P and especially Zn (2.9 and 1.1 mg 100 g^{-1} DW in W50 and W100, respectively) and Fe (5.6 and 2.4 mg 100 g^{-1} DW in W30 and W100, respectively) were highly concentrated in water stressed roots alike NDF and ADF. In contrast, °Brix, pH and total not-structural sugars were reduced by water stress, although the sucrose fractions of fructose and glucose concentrated more in W30 plant roots than W100 (18% and 33% higher, respectively). Red beet showed a strong plasticity in its adaptation to drought thanks to avoidance mechanisms (constrained leaf and storage root development) and tolerance mechanisms (increased FLV and thermal dissipation). Interestingly, the high concentration in phytochemicals and nutrients may contribute to the maintenance of human health and may reduce the risk of chronic diseases.

1. Introduction

Water availability is considered as one of the most important environmental factors affecting plant growth and productivity (Boyer, 1982). Variations in water availability induce morphological, anatomical and physiological responses such as higher leaf and cuticle thickness (Guerfel et al., 2009), adjustments in gas exchange and assimilate translocation (Morgan et al., 2004), alteration in water uptake and evapotranspiration (Katerji et al., 2010), antioxidant reactions (Apel and Hirt, 2004), gene expression and enzyme activity (Jiang and Zhang, 2002). Phenotypic plasticity is considered the major means by which plants cope with environmental change and in particular water stress (Valladares et al., 2007).

Under drought, the changes in plant dry mass allocation patterns often lead to lower leaf area/root biomass ratio changes. These changes relate closely to the water use efficiency (WUE) and acclimation mechanisms to water stress intensity (Navas and Garnier, 2002). Subsequent stomata closure can reduce leaf water potential, thus maintaining water uptake, photosynthesis and growth for as long as possible (Clarke et al., 1993). Indeed, stomatal closure leads to a lower level of water loss per unit of carbon assimilation, thereby improving the WUE in water stressed plants (Gonzáles et al., 2008). However, stomatal closure is also coupled with inhibition of CO_2 flow and nutrient uptake by roots, eventually resulting in reduced photosynthesis and subsequent carbohydrate production (Dunham and Clarke, 1992). In addition, evapotranspiration tends to cease, which in turn raises the temperature of the leaf (Lourtie et al., 1995).

Water stress affects crop quality significantly. In soybean and wheat seed, protein accumulation was respectively inhibited (Rotundo and Westgate, 2009) and increased (Ozturk and Aydin, 2004). In several crops, reduction in starch accumulation was observed under water stress, although the results were very variable (Debon et al., 1998; Bethke et al., 2009). Since water plays an important role in mineral mobilization, water deficit may reduce uptake of Fe, Zn and Cu (Oktem, 2008) although other studies observed higher mineral concentrations (Keutgen and Pawelzik, 2009). In addition, studies dealing with horticultural crops reported increases in antioxidant concentrations under water stress (Favati et al., 2009).

Red beet (*Beta vulgaris* var. *conditiva* Alef.) is a potential source of minerals, antioxidants, sugars, dietary fibers, vitamins, fatty acids and natural pigments that possess several biological activities,

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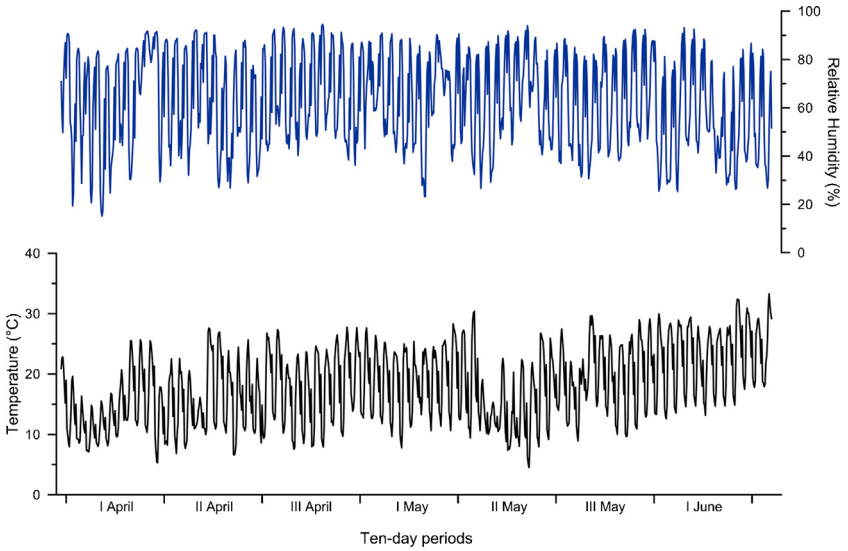

Fig. 1. Patterns of temperature (°C) and relative humidity (%) during the course of experimentation.

including antioxidant, anticancer and radio-protective properties (Escribano et al., 1998). Nevertheless, to date, no studies have been conducted to study the effects of abiotic stress, and particularly water stress, on yield and nutrient accumulation in this crop. A few studies conducted on the subject regard dry matter partitioning (Hole et al., 1984; Benjamin and Sutherland, 1989) but in non-limiting growing conditions. Some works on sugar beet, a crop relative to red beet, showed that the environment strongly affects sugar beet growth, root yield and sugar quality (Tsialtas and Maslaris, 2006; Hoffmann et al., 2009; Tsialtas et al., 2010, 2011). Nevertheless the effect of water shortages on dry matter partitioning is unclear (Abdollahian-Noghabi and Froud-Williams, 1998), although the greatest reduction in dry matter accumulation usually occurs in the storage roots.

Therefore, to study the effects of water stress on the adaptive changes in plant growth, red beets were subjected to three water regimes (100%, 50% and 30% of water holding capacity). The main objectives were to assess the drought tolerance of red beet and the accumulation in roots of elements and molecules with putative biological activity.

2. Materials and methods

Two experiments were carried out from March to mid June 2012, at the greenhouse of Agronomy and Crop Sciences Research and Education Center, Department of Food Science, University of Teramo (42°53′N and 13°55′E, 15 m a.s.l.). Environmental conditions were constantly monitored during the crop cycle (Fig. 1) using temperature and humidity sensors connected to a data logger (EM50 Data Collection System, Decagon Devices, USA).

2.1. Plant material and experimental design

Seeds of red beet (*B. vulgaris* L. var. *conditiva* Alef., cv. Piatta d'Egitto) were sown on a nursery potting soil (Huminsubstrat N3, Neuhaus, Germany) and were irrigated till crop emergence (7 days after sowing). Seven days after emergence, plants were transplanted into 20 cm diameter pots (5 l) at a density of 1 plant/pot. Pots were filled with sphagnum peat moss, perlite and vermiculite at the ratio of 2:1:1.5. At transplanting, simple superphosphate at a rate of 3 kg m^{-3} was incorporated into the potting soil substrate. At 11 and 19 days after transplanting plants were fertilized with an NPK fertilizer 20-20-20 (Linea Master 20.20.20, Valagro S.p.a., Italy) at a rate of 6 g per pot.

The experimental design was a randomized complete block design with three replicates, where three water regimes represented the thesis under comparison, as follows: pots kept at 100% (W100) of water holding capacity (WHC), 50% (W50) of WHC and 30% (W30) of WHC. Each thesis (treatment) consisted of 240 pots (hence, 80 pots represented one experimental unit). The water regimes were imposed starting from the transplanting. Water loss, due to evapotranspiration, was constantly monitored by injecting into the pot soil moisture sensors (EC-5, Decagon Devices, USA), which were connected to a data logger (EM50 Data Collection system, Decagon Devices, USA), in order to maintain the initial water content. The pots were manually re-watered with tap water (pH 7.2, EC 0.23 mS cm^{-1}) every day at 18:00. The soil volumetric water content was maintained at 0.230, 0.115 and 0.069 m^3 m^{-3} for W100, W50 and W30, respectively.

2.2. Determinations of physiological traits

2.2.1. Stomatal conductance

Starting from 19 days after emergence (DAE), the leaf stomatal conductance (mmol m^{-2} s^{-1}) was measured weekly with a steady state diffusion porometer (Model SC-1, Decagon Devices, USA). This hand held porometer measures leaf stomatal conductance (g_s), by electronically timing a given amount of air movement through the leaf under pressure (Rebetzke et al., 2000). Measurements were taken in one fully expanded leaf of four randomly selected plants per experimental unit.

2.2.2. Canopy temperature

Canopy temperature was assessed with a portable infrared thermometer (Everest Interscience Inc., Az, USA) on the day following an irrigation either around midday or in the early afternoon on warm, relatively cloudless days, according to Amani et al. (1996). Temperature was measured with the instruments held at 45° to the horizontal and at a distance of 20 cm from the leaf surface. Measurements were taken on the same leaf of four different plants per experimental unit.

2.2.3. Leaf water content

Following the procedure of Turner (1981), leaf water content (LWC [%]) was calculated as: $LWC\ (\%) = [(FW - DW)/FW] \times 100$];