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Low and high-temperature effects on sweetpotato storage root initiation and early transplant establishment

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ABSTRACT

Temperature is considered as a major environmental factor upon which the storage behavior of sweetpotatoes depends. To quantify shoot and root vigor responses during sweetpotato early transplant establishment, an experiment was conducted using sunlit environmental growth chambers at three day/night temperatures, 22/14 (low), 30/22 (optimum), 38/30 °C (high). Ten sweetpotato cultivars were transplanted in pots for 20 days and several shoot and root morphological and physiological traits were assessed. Sweetpotato cultivars varied significantly for many traits measured particularly root components. High and low temperatures significantly decreased the production of storage root number. Low temperature caused a marked decrease in vine length, node number, leaf area, total biomass, and net photosynthesis causing 95, 70, 78, 66, and 36% reduction compared to the optimum temperature. At high temperature, average leaf area was seven times more than optimum indicating strong temperature effects on leaf number, size, and leaf area development. Principal component analysis was used to classify sweetpotato cultivars to low and high-temperature tolerant, intermediate, and sensitive groups. The sweetpotato cultivars O'henry and Bonita were identified as tolerant, Evangeline, B14, Vardaman, and Covington as intermediate tolerant, and NC05198 and Travis as sensitive to both low and high temperatures. A poor correlation was observed between low and high temperature response indices indicating that cold and heat tolerance mechanisms are different and the selection has to be made independently in developing tolerance to low and high temperatures. The identified low and high temperature tolerant cultivars and their associated morpho-physiological characteristics may be useful for breeders to develop new cultivars that could withstand variable temperatures projected to occur in future climates aiming to increase storage root yield.

1. Introduction

With more than 105 million metric tons in global annual production, sweetpotato (*Ipomoea batatas* (L.) Lam) ranks seventh after wheat, rice, corn, potato, barley, and cassava (FAO, 2016). Although it was originated in Central and/or South America (O'Brien, 1972), world sweetpotato production is mostly centered in Asia where the majority comes from China, with an output of 81 million metric tons (Wang et al., 2015). Production of sweetpotato in the United States has increased substantially over the past decade, with a record high production of 1.4 million metric tons in 2015 (USDA, 2016). Over 90% of sweetpotato cultivation is concentrated in the southeastern U.S. (primarily North Carolina, Louisiana, and Mississippi) thus, it is being considered as a southern crop in the U.S.

The ability of the plant to achieve its maximum yield potential is the function of its interaction with the prevailing environment in which it ends its life cycle (Leon et al., 2016). There is a substantial impact of different environmental factors on the plant processes from metabolism to gene expression during various stages of crop growth (Xu, 2016); hence genotypes differ widely in their responses to environments. The expression of a phenotype and its performance depends upon the magnitude of genotype by environmental interaction (Redden, 2013; Singh et al., 2018). So, it is essential to understand the environmental factors that affect plant growth and yield and implement better

Abbreviations: DAP, days after planting; SPAR, Soil-Plant-Atmosphere-Research; VL, vine length; NOD, node number; LA, leaf area; LW, leaf weight; SW, stem weight; RW, root weight; TD, total dry weight; SR, storage root; LRL, longest root length; RCL, cumulative root length; RSA, root surface area; RD, root diameter; RV, root volume; RNT, root tips; RNF, root forks; RNC, root crossings; Chl, chlorophyll; Flv, flavonoids; Anth, anthocyanin; NBI, nitrogen balance index; Pn, net photosynthesis; gs, stomatal conductance; Tans, transpiration rate; ETR, electron transport rate; Ci/Ca, internal to external CO_2 ratio; Fo, minimal fluoresence; Fm, maximal fluoresence; Fs, steady-state fluoresence; Fv′/Fm′, quantum efficiency

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management strategies to improve the crop performance for a better output. One way to assess crop performance and their responses to environmental factors is phenotyping with the use of high-throughput methodologies and tools. Since most environmental factors are dynamic and continuously varying throughout the growing season; the assessment could be made systematically at different crop growth stages. Similar to most of other agricultural crop growth, sweetpotato has also been shown to be affected by extrinsic environmental stresses, including light (Bonsi et al., 1992; Mortley et al., 2009), temperature (Gajanayake et al., 2014, 2015), CO_2 (Finnan et al., 2008), and drought (Gajanayake et al., 2013; Gajanayake and Reddy, 2016). Among these abiotic stress factors, temperature fluxes have an imperative role in storage root initiation and crop development. Therefore, a systematic understanding of crop responses during stand establishment will be useful in addressing the challenges of cultivar tolerance and to improve new screening tools under varying environmental conditions. Principally, little information is available describing the effects of temperature on sweetpotato lateral root initiation, morphology, growth and developmental related traits at early growth stages. Hence, an understanding of the root system architecture and key traits holds potential to increase storage root yield and optimize agricultural use.

The root system of sweetpotato plants comprises storage roots, pencil roots, and fibrous roots. The fibrous roots provide a proper anchorage and absorb water and nutrients to support above ground growth of the plant. When sweetpotato root initiation begins, some of the lateral roots will develop into storage roots while few of them will become lignified and will develop to pencil roots. The latter will occur predominantly under stress conditions such as water deficit stress and high temperature (Ravi et al., 2009). Under promising conditions, sweetpotato storage root initiation is started 2 weeks after transplanting. Therefore, first 2 weeks to 30 days after transplanting period is very critical in deciding the number of storage roots initiated per plant (Meyers et al., 2017).

High and low temperature extremes play a key role in sweetpotato storage root initiation and bulking at its critical phenophases (Gajanayake et al., 2014). An ample day and night temperature is essential for promoting rapid and uniform sweetpotato root development and good stand establishment. The temperatures between 20 to 30 °C favor storage root initiation and growth of sweetpotato (Ravi and Indira, 1999). Sweetpotato can adapt to more warm temperate climates with the reported thermal optimum to be above 24 °C. The temperature less than 15 °C hinders storage root growth while promoting the fibrous root formation. The highest yields are typically obtained when night time temperature is in between 14–22 °C (Singh and Mandal, 1976; Ngeve et al., 1992). The translocation of sugars from shoot to root occurs during night time, thus, apparently, the nighttime temperature is more critical for storage root growth (Nakatani et al., 1989). Higher nighttime temperature (< 25 °C) promotes shoot growth due to enhanced gibberellic acid production and suppresses storage root formation due to increased IAA activity (Chan, 1988). In contrast, cooler nighttime temperatures favor greater conversion of sucrose to starch in storage roots thus; greater photosynthate partitioning is occurred towards storage roots than to fibrous roots (Eguchi et al., 2003). Being of tropical origin, sweetpotato is more susceptible to low-temperature injury and could not survive the temperature of less than 12 °C (Belehu and Hammes, 2004; Sark, 1978). The most common symptoms of chilling damages include reduced vine growth and leaf growth, fungal decay, internal tissue breakdown and discoloration, root shriveling, greater weight loss, and failure to sprout (Lukatkin et al., 2012).

Root growth and seedling vigor are key aspects of plant development and play a critical role in early season canopy growth and productivity (Reddy et al., 2017; Wijewardana et al., 2016a, 2016b). Increased leaf area is suitable for the maximum light interception to maintain an efficient source (leaf) and sink (storage root) relationship. Unfavorable conditions such as high temperature have been reported to decrease photosynthetic activity; thus, source/sink functions could be altered due to the availability of low amount of sucrose to export (Lemoine et al., 2013). The root system has a crucial role in the early stage plant establishment and performance; therefore, the root system architecture and its components are important, aiming to select cultivars with improved tolerance to environmental limits (Lynch, 1995). Nevertheless, due to the multiplicity of functions, dynamic environmental interactions, vastly organized belowground distribution, and due to extensive and tedious work (Brand et al., 2016) crop selection for tolerance based on root traits is often lacking. Typically, poor root development during plant establishment can reduce shoot growth and canopy development at the later stage of the plant (Gajanayake et al., 2014; Wijewardana et al., 2017). Hence, understanding the possible impacts of early-season temperature fluctuations on root morphology and storage root initiation will benefit to optimize storage root yield and for the enhancements of management practices in the present and future climate scenario. To date, very few studies have been reported the low and high-temperature effects at the early seedling establishment on storage root initiation and development. Therefore, the objectives of this study were to reveal the precise relationships between low, optimum, and high temperatures and shoot and root vigor during sweetpotato early seedling establishment and classify some widely grown sweetpotato cultivars based on their tolerance to different temperature conditions.

2. Materials and methods

2.1. Experimental condition

The experiment was conducted at the Rodney Foil Plant Science Research facility of Mississippi State University, Mississippi State utilizing sunlit environmental growth chambers, also known as SPAR (Soil-Plant-Atmosphere-Research) units. Each chamber possesses a steel soil bin (2 m long by 0.5 m wide by 1 m deep) to house the root system and Plexiglas chamber (2 m long by 1.5 m wide by 2.5 m tall) to accommodate aerial plant parts. The Plexiglas with 1.27 cm thickness enables 97% of the visible solar radiation to pass without spectral changeability in absorption (Zhao et al., 2003). These growth chambers have the ability to accurately control atmospheric CO_2 concentration and air temperatures at preset set points and at near ambient levels of photosynthetically active radiation (PAR). The chamber CO_2 concentration was monitored and maintained at 410 μmol mol^{-1} using a dedicated LI-6250 CO_2 analyzer (Li-COR, Inc., Lincoln, NE). The relative humidity of each SPAR chamber was monitored and calculated according to the procedure of Murray (1967), with a humidity and temperature sensor (HMV 70Y, Vaisala, Inc., St. Louis, MO) installed in the returning path of airline ducts. In order to maintain a constant humidity, the chilled mixture of ethylene glycol and water was circulated through the cooling coils via several parallel solenoid valves located outside the air handler of each chamber that opened or closed depending on the cooling requirement. The heating and cooling system is connected to air ducts that pass conditioned air through the plant canopy to cause leaf flutter simulating field condition. Throughout the treatment period, evapotranspiration rate (ET) of each unit was determined and expressed on a ground area basis (L d^{-1}) (Table 1). The ET was measured at a rate in which condensate was removed by the cooling coils at 900 s intervals by measuring the quantity of water in collecting devices connected to a calibrated pressure transducer (McKinion and Hodges, 1985). The plants were fertigated with full-strength Hoagland nutrient solution (Hewitt, 1952) through an automated drip irrigation system delivered three times a day at 0800, 1200, and 1600 h. The amount of water provided to each treatment was adjusted based on evapotranspiration values recorded on previous day by making changes in the time and duration. Variable density shade cloths (Hummert Seed Co., St. Louis, MO) designed to mimic solar radiation diminution through the plant canopy and positioned around the edges of the plant canopy. These were adjusted regularly to match canopy