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Effect of pine bark volume and ventilation for bell pepper production in high tunnels

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ABSTRACT

Bell peppers cultivated in Florida represent one third of the U.S. fresh-market production. Protected cultivation offers an advantage in a subtropical, humid climate to obtain high-quality colored bell peppers. However, multiple factors such as ventilation, high temperatures, and potting media volume can affect the success of bell pepper production under protected cultivation. The objective of this study was to evaluate the combination of two ventilation types and four pine bark volumes on bell pepper yield, plant growth and fruit quality. No significant effects of ventilation or pine bark volume on plant growth or commercial yield were found. This study suggested bell pepper can be cultivated in small pots as long as the plants are in non-limiting water and nutrient conditions. Moreover, a ventilation system with only a central roof vent in the ridge of the tunnel with a metallic gutter has no additional beneficial effect on colored bell pepper yields.

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1. Introduction

Bell pepper is a key vegetable crop in Florida U.S. with a fresh-market value of $220 million dollars (USDA-NASS, 2016). During 2015, production in Florida accounted for 27% of the total U.S bell pepper production (USDA-NASS, 2016) with the majority of acreage in open field production. High quality pepper fruits are difficult to obtain in open field production because of precipitation, weeds, pests, nematodes, and soilborne diseases (Bowen and Frey, 2002; Cantliffe et al., 2008; Lamont, 2009).

Protected cultivation is a desired method for high-quality red, yellow, orange and purple bell pepper production because of reductions in fruit quality in open field to meet the increasing consumer demand for these commodities (Cantliffe et al., 2008; Jovicich et al., 2005). Growers receive prices up to 3 times higher for colored bell peppers than green bell peppers (USDA-ERS, 2013). Concomitantly, U.S. consumption has increased from 3 kg per capita in 2007 to over 5 kg in 2012 (USDA-ERS, 2013). Currently, this demand is being met with imported produce, accounting for 50% of the domestic U.S. consumption (USDA-ERS, 2013). In Florida's subtropical climate, growers have a marketing opportunity during a time of unsupplied demand in the domestic market and can produce significant tonnage in protected cultivated systems (Cantliffe et al., 2008; Jovicich et al., 2005; USDA-ERS, 2013).

Protected cultivation generally uses soilless culture which reduces the need for soil fumigants and can lead to higher yields (Jovicich et al., 2005, 2004a; Schnitzler, 2004; Stapleton, 1996). There are several options available for soilless substrate such as perlite, coconut coir, and peat moss. However in Florida U.S., pine bark is used as the predominant growing media because it is locally available and is relatively cheap compared with other substrates. This soilless system is used in combination with containers of different volumes, shapes, and materials for vegetable and small fruits production (Jovicich et al., 2004b; Santos et al., 2013). Containers with differing shapes and volumes modify root development and morphology, depending on space available for root growth and growing habits (NeSmith and Duval, 1998). Shallow-rooted plants have different growth habits compared to deep rooted plants when planted in equal volume containers; therefore container shape is an important factor in root development (von Felten and Schmid, 2008). Nevertheless, pepper plants are considered a moderately rooted plant since they have some deep roots with a majority of shallow roots. As pot size increases, water and nutrient availability increase (Poorter et al., 2012). Pot height is important for optimal root growth, as short containers can lead to hypoxic conditions for roots because of the limited air space (Passioura, 2006).

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Protected structures such as high tunnels can be used for frost protection during the winter season or to reduce heat stress during summer months. In Florida U.S. during the late winter and early spring seasons, air temperature can be below 0 °C, while in late spring and summer months, air temperatures over 38 °C. These extreme temperatures can negatively impact plant growth and fruit development, particularly flower pollen and ovary viability, fruit set and fruit shape (Saha et al., 2010). Pollen viability is reduced when air temperatures fall below 15 °C at night and below 18 °C during day (Polowick and Sawhney, 1985). Moreover, nighttime temperatures over 23 °C and daytime temperatures over 28 °C inhibit ovary elongation (Polowick and Sawhney, 1985). Fruit disorders such cracks, misshapen fruit, and color spots are the result of sub- or supraoptimal air temperature, radiation, water and nutrient conditions on the plant (Rylski and Spigelman, 1986); nevertheless, those fruit disorders can be reduced using the proper irrigation and nutrient management maximizing marketable yields (Jovicich et al., 2007). High tunnels, which are being explored for use in Florida U.S., still require an effective method to reduce air temperatures since air temperatures inside a protected structure could be 6 °C warmer than outside depending on air movement (Bartzanas et al., 2004). Although high tunnels have been used for many years worldwide, their use is relatively new in the U.S., especially in Florida where the majority of bell pepper is produced in open fields. High initial costs and structure maintenance are deterrents for growers; yet potential profits can be up to four times greater than open field production (Cantliffe et al., 2008). Additionally, 90% of the farms in the state are small scale farms (up to $250,000 dollars in sales according to the USDA) with little or no experience in vegetable production under protected culture. Therefore research on sustainable vegetable production for high-quality commodities for small- to medium-scale production is needed in order to help growers to increase profits and remain competitive on the market.

The objective of this study was to determine the effect of passive ventilation and container volumes on red bell pepper yield and fruit quality in high tunnels in Florida U.S.

2. Materials and methods

2.1. Experimental conditions and plant material

The study was conducted during two seasons at the Gulf Coast Research and Education Center of the University of Florida, Wimauma, FL U.S., from October 2013 to March 2014 season 1 (S1) and from March 2014 to July 2014 season 2 (S2). Experiments were conducted under high tunnels, each with a surface area of 56.2 m^2. Tunnel dimensions were (5.91 m wide × 9.51 m long × 3.65 m high) oriented in a north-south direction. The structures were built using 7 galvanized pipes as hoops (9.38 m long × 6.35 cm diameter) and 7 wooden poles (0.14 m in diameter × 2.44 m high) for support. The sides were supported by one pole every 1.52 m and structures with passive ventilation had an open roof with 30 cm width at the center with a galvanized canal (0.45 m wide) suspended from the roof (30 cm) by chains for rain capture. The roof covering was clear polyethylene (polyethylene, 0.1524 mm thick, Berry Plastics Corporation, Evansville, IN, U.S.), with 30% sunlight reduction. When frost events were forecasted, the ends of the tunnels were closed 24 h prior for freeze protection with the same plastic used for the roof, and opened when the air temperature reached 15 °C outside the high tunnels. This was repeated each time a frost advisory or event was predicted.

Pine bark particle size was between 1 to 2.5 cm in diameter (Elixson Wood Products, Starke, FL, U.S.). Black high-density polyethylene number 2 (HDPE 2) containers were used and had four different volumes: 1) 3.92 L (19.05 cm top diameter × 15.4 cm bottom diameter × 18.4 cm high), 2) 6.52 L (21.6 cm top diameter × 18.6 cm bottom diameter × 21.6 cm high), 3) 11.20 L (27.9 cm top diameter × 22.7 cm bottom diameter × 24.4 cm high) (Myers Industries Lawn & Gardening Group, Middlefield, OH,U.S.) 4) 14.55 L (28.7 cm top diameter × 24.8 cm bottom diameter × 28.2 cm high) (Nursery Supplies Inc., Kissimmee, FL U.S.). The combination of two ventilation systems (passive/non-passive) and four container volumes for a total of eight treatments. Treatments were arranged in a split-plot design with ventilation system as the main factor and pine bark volumes as the sub-factor. Experimental units (tunnel) were 56.2 m^2 with three tunnels per ventilation system (replicates), each subplot was 4.26 m long × 0.6 m wide (26 plants in double rows). Each subplot was separated 1.22 m between row centers. In-row spacing was 0.3 m with double rows separated 0.3 m apart, corresponding to a plant density of 5.4 plants m^{-2}.

Determinate 'Revolution' bell pepper (Speedling Inc., Sun City, FL, U.S.) seedlings (7 week-old) were transplanted on 29 Oct., 2013 (S1) and 17 Mar., 2014 (S2). Pre-plant nitrogen (N) was applied at a rate of 50 kg ha^{-1} using liquid calcium nitrate ($CaNO_3$; 9% N, Chemical Dynamics, Inc., Plant City, FL, U.S.) as the N source, applied through the irrigation system. The electrical conductivity (EC) of the pine bark ranged from 2 to 2.5 mS cm^{-1} after pre-plant application (HI 98130 pH, conductivity/TDS tester, Hanna® instruments, Carrollton, TX, U.S.). Irrigation was used 8 h day^{-1} for 5 days to establish bell pepper seedlings for S1 and S2 with a flow rate of 18.1 L h^{-1} (Spot-Spitters®; 160° Spray Stick, 18.1–23.8 L/h, Lt Green; John Deere Water Tech., San Marcos, CA, U.S.). The irrigation was adjusted after establishment according to the evaporative requirements, stage of growth, and potential evapotranspiration (ET_o) requirements from historical data in west-central Florida U.S. (Simonne et al., 2011). Plants were fertigated using a fertilizer injector (Model D25RE09, Dosatron®, Clearwater, FL, U.S.) on a daily basis. Each plot received approximately 225 kg $ha^{-1}$of N per season divided in 2 injections, one with the first irrigation and the second with the last irrigation cycle each day according to their phenological stage. The fertilizer solution used contained 6% N; 2% P; 8% K; 2% Ca; 0.4% Mg; 0.02% B; 0.04% Mn; 0.020% Zn; 4.5% Cl (Chemical Dynamics Inc., Plant City, FL, U.S.). The pH of the pine bark ranged between 6.8 and 7.2, and EC ranged from 1.5 to 2.5 mS cm^{-1} during the time this study was conducted. The plots were individually tied horizontally to galvanized poles on the edges with plastic strings every two weeks starting 5 weeks after transplanting (WAT) without any pruning. Imidacloprid, thiamenthoxam, and abamectin were applied to control pest populations according to labels targeting principally aphids (*Myzus persicae* Sulzer), pepper weevil (*Anthonomus eugenii* Cano), whitefly (*Bemisia* sp.), and broad mite (*Polyphagotarsonemus latus* Banks) which are the main pests in Florida bell pepper production (Ozores-Hampton et al., 2014).

2.2. Variables measured and experimental design

Plant height was measured at 2, 4, 6, 8, 10 and 12 WAT using the same five plants per plot randomly selected. Height (cm) was measured from the growing media level in each pot to the most recently expanded top leaf at the tip of the point growing. Shoot and root dry weights were measured at 4, 8 and 12 WAT using destructive harvest of two plants per replicate. Roots were gently washed with water to separate the growing media from the root systems. Shoots and roots were oven-dried (80 °C for 7 d) and weighed.

Tissue analysis for nitrogen (N), phosphorus (P) and potassium (K) evaluation was conducted at 8 and 12 WAT, with 20 randomly selected, most recently fully expanded leaves per replicate. Leaves were oven-dried and ground (80 °C for 7 d) (3383L20 Thomas Willey® Mini-mill, Swedesboro, NJ, U.S.) before being sent to a commercial laboratory (Waters Agricultural Laboratories, Inc.,