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Strawberry cultivars vary in productivity, sugars and phytonutrient content when grown in a greenhouse during the winter

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ABSTRACT

In many areas of the US, fresh locally grown berries are not available during the winter. With this in mind, a research study comprised of three experiments was conducted focused on cultivar selection for berry yield, number, sweetness and phytonutrient content. Using a capillary mat system with under bench heating within a double-layer polyethylene greenhouse, strawberries were grown in the Great Plains Region of the US during the winter. During experiment 1, 12 cultivars were grown; berries were weighed, counted and analyzed for sugars and phytonutrients. 'Albion' plants produced a high number/mass of berries, had relatively high sugar content but a lower level of phytonutrients when compared to other cultivars. Sugar and phytonutrients concentrations overlapped across cultivars and thus, one cultivar could not be statistically singled out as best. As all cultivars flowered and fruited, two additional 8-month-long experiments were conducted. It took only 7 weeks from potting of dormant crowns for most cultivars to produce fruit. Certain cultivars fruited more successfully during certain months than others, but this was not associated with response time. For example,' 'Albion', 'Chandler', 'Darselect', 'Evie-2′ and 'Seascape' plants consistently produced fruit October to early January while 'AC Wendy', 'Cavendish', 'Honeoye' and 'Strawberry Festival' plants mainly produced berries in March/April. Summed over experiment 2, 'Albion', ' Cavendish', 'Chandler', ' Evie-2', 'Portola' and 'Seascape' plants produced the greatest mass of berries. 'AC Wendy' and 'Darselect' berries contained some of the highest levels of sugars while berries from 'Chandler', 'Darselect', 'Evie-2', 'Seascape' and 'Strawberry Festival' had some of the highest phytonutrient values. In the third experiment, of the 8 selected cultivars, 'Evie-2′, 'Evie − 2 + ' and 'Portola' plants had the highest total yield and average berry mass/plant. 'Seascape' and' Chandler' plants were second in total production. Glucose, fructose and sucrose levels varied across cultivars with 'Chandler' and 'Seascape' berries possessing the lowest level of total sugars. Phytonutrient values varied among cultivars with some having better flavonoids ('Seascape'), phenols ('Seascape' and 'Chandler') and ant oxidant capacity ('Seascape', 'Evie-2' and 'Cavendish'). Measurement of soluble solids concentration varied by week among the cultivars with 'Seascape', 'Seascape + ", and "Albion" berries possessing higher levels than other cultivars such as 'Cavendish'. Overall, under these winter greenhouse conditions using capillary mat fertigation and an under-bench heat delivery system, strawberries were successfully produced for the off-season market.

1. Introduction

Strawberries are one of Americans' favorite fruits and shoppers are accustomed to always having berries available in the grocery store. In 2011, 81% of fresh marketed strawberries were grown domestically. However, to meet consumer demands, 394.2 million pounds of fresh and frozen strawberries were also imported from Mexico during the winter season (Boriss et al., 2010). With increasing shipping costs and seasonal price peaks near holidays, such as Thanksgiving and Christmas, and the influence of the local food movement, winter-grown strawberries present an opportunity for increasing and diversifying regional food production. In addition to their popularity as a fresh fruit, strawberries are ideal for winter greenhouse production because berries can be frozen, made into jam or jellies, wine, candy, syrup or glazes, ice

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cream and fragrance products. As a first step towards year-round production, Mattas et al. (1997) examined the economic feasibility of extending the harvest season. They observed that although strawberries grown in perlite and turf soilless culture gave a higher yield than the conventional soil system, the gross profit was not enough to offset the investment. Ballington et al. (2008) reported that in the mid-south US, using plastic mulch and four day-neutral cultivars, ‘Albion’ plants produced the highest yield and superior quality fruits. However, they also concluded that at the current market price, it was not profitable to extend the production season of strawberries. In Utah, Rowley et al. (2011) reported a marginal profit after testing four day-neutral cultivars. ‘Evie 2’ and ‘Seascape’ plants gave the most consistent yields and acceptable fruit size when grown in high tunnels, particularly when compared to an economic loss for crops that were field-planted.

The above studies focused on season extension using high tunnels rather than l winter greenhouse production of strawberries. While research and actual winter production has been limited in the USit has not been in Europe (Takeda and Hokanson, 2002; ; Pritts and Handley, 1998). Countries such as The Netherlands and Belgium have been growing strawberries in buckets and peat bags in greenhouses for decades (Lieten, 1993; Mattas et al., 1997). Thus, it is feasible that regions of the US with high winter light conditions, such as the Great Plains, could allow for winter berry production.

However, heat costs could still limit profitability. Therefore, we designed a resource conservation-minded growing system that minimizes water, fertilizer and heat usage and maximizes light reflectance to determine whether we could grow and produce strawberries during the winter season (Paparozzi, 2013). In addition to developing an affordable production system, suitable for any smaller specialty crop farmer, we wanted to evaluate the sweetness and health benefits of potential cultivars that could be grown in our system. With the off-season production goal of obtaining the highest price for the berries, the purpose of this research was to select strawberry cultivars that would produce the most mass and number of berries with the highest phytonutrient content without sacrificing sweetness when grown in a greenhouse during the winter.

2. Materials and methods

Three experiments were completed during winter 2009-spring 2010 (experiment 1–screening experiment), fall 2010 through spring 2011 (experiment 2–cultivar trial), and fall 2011 through spring 2012 (experiment 3–focused trial on successful cultivars). All experiments were conducted in a 7.2 × 29 m double-polyethylene covered Quonset-style greenhouse on the East Campus of the University of Nebraska – Lincoln (UNL)(lat. 40°50′N, long. 96°45′W). Plants were grown on two separate 1.8 × 18.3 m benches oriented north-south with a capillary mat system (CapMat™II, Phytotronics®, Inc., Earth City, MO) used for fertigation (Lambe et al., 2012; Paparozzi and Meyer, 2012). The capillary mat system consisted of a bottom layer of 0.15 mm (6-mil) thick multipurpose black plastic sheeting (Polar Plastics Inc., Oakdale, MN), followed by fibrous mat, fed by 0.200 mm (8-mil) thick RO-DRIP® drip tubes with 20 cm spacing (John Deere, Moline, IL) on the mat, and then covered with white top/black bottom polyethylene film (Panda Film ™, Flora Hydroponics, Atlanta, GA). The top plastic film served as a reflective mulch and vapor barrier (Meyer et al., 2012). Fifteen-centimeter plastic pots with bottom holes were interfaced with the mat by using a special jig device to cut holes in the top plastic for each pot by using an X-ACTO® knife blade (Elmer’s Products, Inc., Westerville, OH) as a pivot cutter to scribe the hole to the correct diameter (for description of jig device see Meyer et al., 2010; Adams and Paparozzi, 2014). Pots were spaced at 27.9 cm on center between rows and 40.6 cm on center between pots occupying a total area of 0.12 m^2 per pot. Benches were hand-constructed from 1.82 m wide bench fabric (Southeastern Wood Products Company, Griffin, GA) on a wooden frame and set on standard-sized concrete blocks to a height of approximately 1 m. The UNL blended potting mix (soil-lite) was comprised of 33% perlite, 33% vermiculite, 28% peat, and 6% field soil to which dolomitic limestone and Micromax micronutrient blend (Scotts, Marysville, OH) were added. Fertigation applications were made using 100 mg nitrogen (N) L^{-1} Jack’s Professional® 20N-8.8P-16.6 K general purpose fertilizer (J.R. Peters, Inc., Allentown, PA) alternating with calcium nitrate at 100 mg N L^{-1} (15.5N-0P-0 K)(YaraLiva™ CALCINIT™ greenhouse grade, Tampa, FL), or tap water as determined from plant observations. An Orbit® 91024 model timer (Orbit Irrigation Products, Inc., Bountiful, UT) periodically initiated fertigation (usually twice per day for 2 min). A SuperDos 30 Model 2.5% Professional injector (Dosmatic U.S.A., Carrollton, TX) with a 100x proportioner was used. Daily watering schedules were adjusted according to crop and environmental conditions to minimize night-time humidity levels and to reduce plant disease and pest pressure.

An active greenhouse ventilation system and 2 forced-air gas furnaces (Modine, Racine, WI) with blowers and directed flashing were attached to 0.5 m diameter polyethylene tubes mounted underneath each bench. These were controlled by a Groton II system (ACME Engineering and Manufacturing, Inc., Muskogee, OK). A day/night temperature differential was kept in the greenhouse at 21/17 °C. A small shaded pole blower was used to take in outside air and blow it between the two layers of polyethylene covering. The greenhouse was fully instrumented to monitor inside and outside temperature, humidity, inside photosynthetically active radiation (PAR) amounts, heat energy used, ventilation, and water/fertilizer utilization events (Meyer et al., 2012). Further, a webcam was used to monitor the plants’ growth throughout the experiments. There were no other plants or experiments in the house. The computer monitoring system recorded no light contamination at night.

Based on advice from colleagues and growers, cultivars were selected of both day-neutral and June-bearing strawberries (Table 1) to determine those best suited for sustainable crop production. Bumblebees, *Bombus impatiens* NATUPOL© (Koppert Biological Systems, Inc., Howell, MI) were introduced into the greenhouse to enhance pollination once the first flowers began to open.

2.1. Experiment 1 winter 2009-spring 2010

The purpose of this screening experiment was to determine if strawberries would flower and fruit in the greenhouse during the winter. It was conducted in 2 phases. In the first phase plants were

Table 1
Strawberry cultivars that were grown in each of the three experiments. Response type is indicated by the superscripts. An asterisk indicates a different source for the crowns. The plus (+) indicates a grade of crowns that possesses a larger root system (as per supplier).

Expt. 1 Winter 2009-Spring 2010	Expt. 2 Fall 2010 – Spring 2011	Expt. 3 Fall 2011 – Spring 2012
AC Wendy[a]	AC Wendy[a]	Albion[b]
Albion[b]	Albion B[c,b]	Cavendish[a]
Cavendish[a]	Albion M[c,b]	Chandler[a]
Chandler[a]	Cavendish[a]	Evie – 2[b]
Darselect[a]	Chandler[a]	Evie – 2[d,b]
Evie – 2[b]	Clancy[a]	Portola[b]
Honeoye[a]	Darselect[a]	Seascape[b]
KRS – 10[a]	Evie – 2[b]	Seascape[d,b]
Seascape[b]	Honeoye[a]	
Strawberry Festival/July[a]	Portola[b]	
Strawberry Festival/ August[a]	Seascape F[c,b]	
Sweet Charlie[a]	Seascape N[c,b]	
Tribute[b]	Strawberry Festival[a]	

[a] June-bearing.
[b] Day neutral.
[c] Indicates different sources.
[d] Premium Grade.