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Phenology, Yield, and Fruit Quality of Floricane–fruiting Blackberry Cultivars under High Tunnel and Net House Production Systems in Florida

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Blackberry (*Rubus* subgenus *Rubus* Watson) blooming and fruit development can be adversely affected by heavy precipitation and excessive heat under subtropical climates in Florida. High tunnels or net houses may protect blackberry plants from these undesirable weather conditions. Our objective is to examine the effects of the two production systems on microenvironments, phenology, yield, and fruit quality of three floricane–fruiting blackberry cultivars, 'Natchez', 'Navaho' and 'Ouachita'. Trials were conducted in Balm, FL in 2016–2017. Although bud break was delayed in all cultivars by 3 to 19 days under the high tunnel tcompared to under the net house, subsequent floricane development was accelerated under the high tunnel, advancing the first harvest date in 'Navaho' and 'Ouachita' by 7 and 11 days, respectively. 'Natchez' produced approximately 6 and 9 times higher marketable yield than the other cultivars under the high tunnel (932 vs. 158–159 g/plant) and the net house (1027 vs. 110–112 g/plant), respectively. The average fruit size was 39% and 24% heavier in 'Natchez' and 'Ouachita', respectively, under the high tunnel than under the net house, whereas that of 'Navaho' was similar under both production systems. Total soluble solid (TSS) concentration was 40% higher in 'Navaho' and 'Ouachita' than in 'Natchez' under the net house, but it was similar in all cultivars under the high tunnel. These results suggest several advantages of growing blackberry under high tunnels rather than under net houses, including improved earliness and increases in average fruit size, yield, and TSS, but the extent of these advantages depends on cultivars.

Blackberry originates from many temperate regions, such as the United States, Europe, North Africa, and Northeast Asia (Moore and Skirvin, 1990). Blackberries are an excellent source of anthocyanins and other phenolic compounds, mainly flavonols and ellagitannins, which contribute to its high antioxidant capacity and other biological activities (Kaume et al., 2012). Because of the health benefits of these antioxidants, consumer demand for blackberries has increased rapidly in recent years (Clark and Finn, 2014).

As a result, blackberry production areas in the United States has increased from 6000 acres in 2012 to 7000 acres in 2016 with 6 million pounds of fresh blackberries valued at $5 million dollars (USDA, 2018a). However, the national production has not satisfied consumer demands, especially during the off-season. In 2017, Mexico exported 154 million pounds of fresh blackberries valued at $286 million dollars to the U.S. market. In Florida, blackberry production areas increased from 167 acres in 2007 to 306 acres in 2012, but it remains to be limited primarily to home gardens and small U-pick operations for local markets (Andersen and Crocker, 2017; USDA, 2018b).

Although there has been increased interest in growing blackberry in the southeastern United States (Safl Ey et al., 2006), production guidelines are limited in this area especially for subtropical climates. In Florida, blackberry plants typically develop flowers and produce fruits from April to July, when the climate is characterized by high temperature and rainfall. Under such undesirable climatic conditions, blackberries are subjected to sunscald and rain damage, adversely affecting fruit quality and limiting marketable yields. In the 2017–18 season, for example, about 30% of yield loss was due to rain damage at one of commercial blackberry orchards in the central Florida (Lin and Agehara, unpublished data).

Protected culture can mitigate the negative impact of inclement weather on crop yield and quality by providing physical protections and environmental modifications. Shade nets (NH) are often used to reduce heat stress and sunburn in plants by reducing and scattering radiation (Stamps, 2009). High tunnels (HT) protect plants from rainfall, wind or hail, and improve fruit earliness and quality of several small fruits (Demchak, 2009). In Florida, compared with the open-field-production, shading treatments increased yields and quality of bell pepper (Hochmuth et al., 2010) and citrus (Jifon and Syvertsen, 2001), whereas a high tunnel improved earliness and increased fruit size, TSS concentration, and marketable yields in strawberry (Salamé-Donoso et al., 2010). However, no information is available addressing blackberry production under protected culture to avoid unfavorable subtropical climates and to improve fruit quality. The objective of this study was to compare phenology, yield and the fruit quality under net houses and high tunnels in Florida.

Materials and Methods

Plant materials. Three floricane-fruiting cultivars, 'Natchez', 'Navaho' and 'Ouachita', were used as experimental materials. Plants were established 0.6 m apart in wooden planters (3.7 m length × 0.6 m width × 0.3 m height) filled with aged pine bark in Apr. 2013 under a net house (NH) covered by 40% black shade

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Table 1. The phenology of ‘Natchez’, ‘Navaho’, and ‘Ouachita’ grown under a net house and a high tunnel in the 2016–17 season.

	First bud break		First bloom		First harvest	
Cultivar	Net	Tunnel	Net	Tunnel	Net	Tunnel
‘Natchez’	16 Mar. b[z]	5 Apr. a	26 Mar. b	6 Apr. a	13 May b	16 May a
‘Navaho’	27 Mar. ab	5 Apr. a	23 Apr. a	18 Apr. a	10 June a	3 June a
‘Ouachita’	3 Apr. a	6 Apr. a	28 Apr. a	17 Apr. a	11 June a	31 May a

[z]Means within a column and each production system followed by the same letter are not significantly different by Tukey–Kramer Test at $P < 0.05$.

nets above. Plants were grown in 60-cm-diameter × 30-cm-high plastic pots, with pots spaced every 0.9 m under a single-bay plastic-covered high tunnel (HT) (45 m long × 7.8 m wide × 4.5m high). Sidewall curtains were open at 1.5 m height to facilitate cross-ventilation. Row spacing was 1.8 m under both production systems. A T-trellis made from pressure–treated lumber was used for trailing blackberry canes. Standard production practices recommended for southeast bramble production were used (Krewer and Fernandez, 2008).

Experimental site. This study was conducted at the Gulf Coast Research and Education Center, University of Florida/IFAS in Balm, FL during the 2016–2017 season. The accumulation of chill hours (air temperature < 7.2 °C) was 91 hours during the winter.

Phenology. Date of first bud break, first open flower and first ripening fruit were recorded according to Hussain et al., (2016) every two days from 20 Mar. to 10 July 2017 under the net house, and every four days from 3 Apr. to 10 July 2017 under the high tunnel.

Yield. All plots were harvested weekly from May to June 2017. Fruits were graded based on USDA standards (USDA, 1997). Fruits were classified as large at ≥ 5 g or small fruits at < 5 g. Marketable fruits included both large and small fruits, when external quality met the requirements for the U.S. No. 1s. Unmarketable fruits included misshapen, overripe, and insect-damaged berries. Number and fresh weight were recorded for each category of fruit.

Fruit quality. At each harvest, the four largest berries were sampled per plot to measure total soluble solid (TSS) concentration using a digital refractometer (PAL-1; ATAGO, Tokyo, Japan).

Experimental design. In both net house and high tunnel trials, treatments were three floricane-fruiting cultivars. Within each production system, treatments were arranged in a randomized complete-block design with four replicated plots per treatment. Each plot consisted of 6 plants under the net house and 3 plants in the high tunnel.

Statistical analysis. Because the production systems were not replicated, statistical analysis was performed among the three cultivars for each production system. All data were subjected to analysis of variance analyses procedure (PROC MIXED) in SAS (version: SAS Enterprise Guide 7.1; SAS Institute, Cary, NC, USA), and P values less than 0.05 were considered statistically significant. The percentage data were transformed by arcsine square root transformation before analysis. Multiple comparisons of least squares means were performed by the Tukey–Kramer test in the MIXED procedure.

Results

Bud break of all tested cultivars was delayed under the high tunnel compared to the net house (Table 1). Under the high tunnel, although bud break was delayed by 3 to 19 days, more synchronized bud break was observed beginning on 5 Apr. 2017 in all cultivars. In contrast to bud break, the onset of flowering and harvest showed different responses to the production systems among the tested cultivars. Under the net house, the dates of first bloom and harvest of ‘Navaho’ and ‘Ouachita’ were significantly later than those of ‘Natchez.’ They were not statistically different under the high tunnel. The first bloom of ‘Natchez’ was delayed by 11 days under the high tunnel, whereas ‘Navaho’ and ‘Ouachita’ bloomed 5 and 11 days earlier than under the net house, respectively. Similarly, the first harvest of ‘Natchez’ was delayed by 3 days under the high tunnel, whereas, those for ‘Navaho’ and ‘Ouachita’ occurred 7 and 11 days earlier than the net house, respectively.

The marketable yield of ‘Natchez’ was significantly greater than that of ‘Navaho’ and ‘Ouachita.’ No difference in marketable yield was observed between ‘Navaho’ and ‘Ouachita’ under both production systems (Fig. 1.) The yield of each cultivar responded differently to the two production systems. Under the high tunnel,

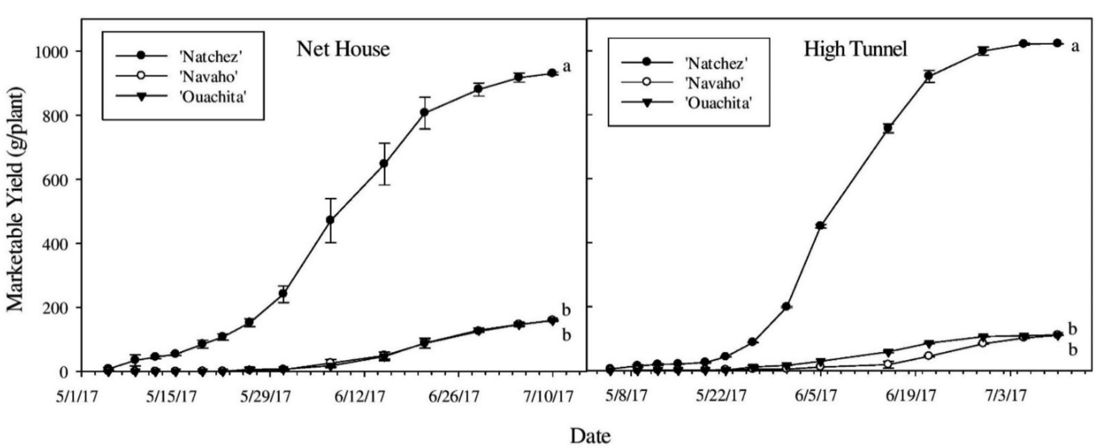

Fig. 1. Marketable yield of ‘Natchez’, ‘Navaho’ and ‘Ouachita’ blackberries grown under a net house and a high tunnel. Means followed by the same letter are not significantly different by Tukey–Kramer test at $P \leq 0.05$.

Table 2. The fruit size of large and small fruits, average fruit size, and total soluble solid (TSS) concentration of 'Natchez', 'Navaho', and 'Ouachita' grown under a net house and a high tunnel in the 2016–17 season.

	Large fruit (g/fruit)		Small fruit (g/fruit)		Average fruit size (g/fruit)		TSS (°Brix)	
Cultivar	Net	Tunnel	Net	Tunnel	Net	Tunnel	Net	Tunnel
'Natchez'	6.77 a[z]	8.11 a	3.49 a	3.49 a	4.87 a	6.77 a	8.45 b	10.90 a
'Navaho'	5.48 b	6.11 b	2.46 b	2.60 b	2.63 c	2.79 c	11.82 a	11.28 a
'Ouachita'	6.06 ab	6.26 b	2.94 ab	3.30 a	3.42 b	4.23 b	11.86 a	11.36 a

[z]Means within a column and each production system followed by the same letter are not significantly different by Tukey–Kramer Test at $P < 0.05$.

Table 3. The proportions of marketable (large and small) and unmarketable fruits in total yield of 'Natchez', 'Navaho', and 'Ouachita' grown under a net house and a high tunnel in the 2016–17 season.

	Marketable wt (%)		Large fruit wt (%)		Small fruit wt (%)		Unmarketable wt (%)	
Cultivar	NetTunnel	Net	TunnelNet	TunnelNet	Tunnel			
'Natchez'	94.6 a[z]	86.2 a	49.3 a	69.6 a	36.1 b	13.2 c	4.0 a	13.2 a
'Navaho'	95.1 a	79.8 a	9.9 c	8.6 c	76.4 a	69.2 a	4.4 a	19.7 a
'Ouachita'	96.8 a	86.8 a	25.0 b	38.2 b	68.9 a	43.7 b	2.8 a	12.6 a

[z]Means within a column and each production system followed by the same letter are not significantly different by Tukey–Kramer Test at $P < 0.05$.

'Natchez' produced 10% greater marketable yield [932 (NH) vs. 1026 (HT) g/plant], but 'Navaho' (110 vs. 158 g/plant) and 'Ouachita' (112 vs. 159 g/plant) produced 30% less marketable yield compared to the net house.

The average fruit size was consistently the greatest in 'Natchez' regardless of production system (Table 2). The average size of marketable fruit of 'Natchez' was 85% to 42% and 143% to 60% greater than other cultivars under the net house and the high tunnel, respectively. The average fruit size was generally greater under the high tunnel than under the net house. The fruit size increase was 39% in 'Natchez' [4.87 (NH) vs. 6.77 (HT) g], 6% in 'Navaho' [2.63 (NH) vs. 2.79 g (HT], and 24% in 'Ouachita' [3.42 (NH) vs. 4.23 (HT) g] for a marketable fruit, 20% in 'Natchez' (6.77 (NH) vs. 8.11 (HT) g), 12% in 'Navaho' [5.48 (NH) vs. 6.11 (HT) g], and 3% in 'Ouachita' [6.06 (NH) vs. 6.26 (HT) g] for large fruit, and 6% in 'Navaho' [2.46 (NH) vs. 2.60 (HT) g], and 12% in 'Ouachita' [2.94 (NH) vs. 3.30 (HT) g] for a small fruit.

The TSS concentration was 40% higher in 'Navaho' and 'Ouachita' than 'Natchez' under the net house, but it was similar among all cultivars under the high tunnel (Table 2). The TSS concentrations of 'Navaho' and 'Ouachita' were similar between both production systems, but TSS concentration of 'Natchez' grown under high tunnel was 29% higher than the net house (10.90 vs. 8.45 °Brix).

The proportion of marketable yield (% total yield, wt/wt) was not significantly different among cultivars under both production systems (Table 3). On average, plants produced a higher proportion of marketable yield under the net house than the high tunnel. The proportion of marketable yield was 96% under the net house and 84% under the high tunnel, averaging across cultivars.

Effects of the production systems on the proportions of large and small fruits appeared to vary among cultivars. Under the high tunnel, the proportion of large fruit increased from 49% to 70% in 'Natchez' and from 25% to 38% in 'Ouachita', by contrast, decreased from 10% to 9% in 'Navaho' compared with the net house. The proportion of small fruit decreased from 36% to 13% in 'Natchez', from 76% to 69% in 'Navaho' and from 69% to 44% in 'Ouachita' compared with the net house.

The proportion of unmarketable fruits was not significantly different among cultivars under both production systems (Table 3). A higher proportion of unmarketable fruits was observed under the high tunnel than the net house in all cultivars (Table 3). Under the high tunnel, averaging across all cultivars, more than 15% unmarketable fruits were found under high tunnel, but only 2% to 4% unmarketable fruits were observed under the net house.

Discussion

Because most blackberry cultivars require 300–900 cumulative chill hours under 7 °C to induce bud break, sufficient chill hours are critical to achieve high blackberry yields (Stephens et al., 2009; Takeda et al., 2002). The reported chilling requirements of 'Natchez', 'Navaho' and 'Ouachita' are about 300, 800–900 and 400–500 hours, respectively (Drake and Clark, 2000; McWhirt, 2016). However, accumulated chill hours in Balm were only 91 hours during the experimental period. In this study, 'Natchez' produced 6 to 9 times higher marketable yields than other two cultivars under both production systems. This result confirms the relatively lower chilling requirement of 'Natchez', and suggests that it is one of the most suitable cultivars for the subtropical climate in the central Florida.

Responses of blackberry phenology to the two production systems were cultivar-specific. The high tunnel delayed bud break but improved fruit earliness by shortening time to flower and harvest especially in 'Navaho' and 'Ouachita' (Table 1), indicating the high tunnel accelerated development of flower laterals and fruit development in these two cultivars. The phenology could be affected by protected culture, for example, the harvest was advanced up to 7 days in 'Navaho' and 11 days in 'Ouachita', but the effect on yield was practically insignificant.

Sunscald is a physiological fruit disorder caused by exposure to excessive sunlight. In this study, compared with the high tunnel, the net house was useful to consistently reduce proportions of unmarketable fruits across all cultivars (Table 3). Sunscald is associated with excess solar radiation and is usually observed when temperature exceeds 32 °C (McWhirt, 2017). Ambient monthly maximum air temperatures exceeded 32 °C after April 2017 (data not shown). The high tunnel tends to accumulate heat under the plastic cover, which may induce greater incidence of sunscald; whereas the advantages of net house include reduction in excess solar radiation and temperature, and increased relative humidity, which mitigate heat stress in plants (Stamps, 2009). In this study, the light intensity under the net house was reduced by 34 to 42%, but temperature was not significantly different from ambient temperature (data not shown). Therefore, the reduction in light intensity under the net house was likely a main contributing factor to suppress sunscald damage in blackberries.

Because fruit yields of 'Navaho' and 'Ouachita' were extremely limited by their high chilling requirements, the two protected production systems did not result in any practical improvements for these two cultivars. It is likely that both 'Navaho' and 'Ouachita' are not suitable to the central Florida's climate. In 'Natchez', the net house and the high tunnel demonstrated different advantages to improving marketable yields: the net house is effective in reducing sunscald damage, whereas the high tunnel is beneficial to increase fruit size and yield.

In conclusion, insufficient chill hours are the major limiting factor for blackberry production in central Florida. Cultivar selections based on chilling requirements should be used for profitable blackberry production in Florida. Benefits of protected culture likely vary depending on the seasonal weather conditions. In areas or seasons with heavy rain, the high tunnel would be useful to increase fruit size and prevent rain damage to fruit. In areas or seasons with dry and hot conditions, the net house would be suitable to lower the incidence of sunscald and improve marketable yield.

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