1-2017

Strawberry Variety Evaluation for High Tunnel Production in Southwest Indiana

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Strawberry production in Indiana primarily utilizes matted row systems, in which bare root strawberry plants are set in the spring, fruit is first harvested in the second year and plants are maintained for a few seasons. Strawberry production using an annual plasticulture system is popular in the southern states because it has a longer harvest period and produces strawberries with better quality. Growers in Indiana have expressed interest in annual plasticulture systems but short fall weather conditions pose a challenge for strawberry plants to reach the desirable size to be able to achieve the optimal yield the following spring. High tunnels that provide additional heat units and moderate frost protection are an effective tool for season extension. The protected cultural practices extend strawberry production season and improve fruit shelf life (Lamont 2009), making strawberries one of the most widely grown small fruit crops in high tunnels worldwide. The objective of this study is to evaluate the performance of strawberry varieties grown in annual plasticulture systems under high tunnel conditions in southwest Indiana.

Materials and Methods

The experiment was conducted in the 2015-2016 season in a 30 ft. wide and 96 ft. long high tunnel in Vincennes, IN. Ten strawberry cultivars were evaluated in the study. Among them, 'San Andreas', 'Albion' and 'Sweet Ann' are day-neutral cultivars. 'Florida Radiance', 'Benicia', 'Camarosa', 'Camino Real', 'Chandler', and 'Strawberry Festival' are June-bearing cultivars. Strawberry plugs were planted on 27 Aug. 2015 on raised beds. Randomized complete block design with three replications and 22 plants per variety per replication was used in the experiment. Strawberry plugs were planted in two rows on each bed. The distance between the two rows was 10 inches. Plants were spaced 14 inches within each row. 60 lb Nitrogen/acre using urea, 1 lb Boron/acre from Boron 14.3% and 2 lb Zinc/acre from Zinc sulfate were applied preplant. Fertigation was based on plant tissue test results. On average, 0.5 lb Nitrogen/acre/per day was applied starting in March by using potassium nitrate, calcium nitrate and urea-ammonium nitrate 28%. A total amount of 5 lb Magnesium/acre with Epson salt was applied in March and April. Pests were managed using recommendations from *Midwest Fruit Pest Management Guide 2016*. Yellow striped armyworms were controlled using Agree WG®. Torino®, Quintec®, and Rally® were used for controlling powdery mildew. Captan® and Scala® were sprayed for gray mold. 2,000 predatory mites (*Phytoseiulus persimilis*) were released in September, 2015. Oberon®, Acramite® and M-Pede® were sprayed to control two-spotted spider mites in the spring.

Row covers were applied at night when the temperature was expected to be lower than 32 °F and 50 °F in fall and spring, respectively, and taken off during days when the temperatures inside high tunnel were above 65 °F. Runners were pruned and recorded weekly. Harvest was conducted once a week during the fall and winter when there were ripe berries, and twice a week from the middle of April to the end of May. Five fruit per variety per replication were selected during peak harvest to measure fruit quality attributes, including total soluble solids (TSS), pH,

titratable acidity and flesh firmness. TSS was measured with a digital refractometer, pH and titratable acidity were measured using an 877 Titrino Plus system, and flesh firmness was measured with a handheld penetrometer.

Results and Discussion

The highest temperatures recorded in high tunnels were above 110 °F for about a week in early September, which caused 21.2% death of 'Benicia' plants, and 15.1% death of 'Sweet Ann' plants. No death of 'Camino Real', 'Festival' and 'Sweet Charlie' plants were observed (Table 1). Dead plants were replanted on 10 September. It should be noted that temperature inside high tunnels can reach a very high level when temperatures outside of high tunnels are above 90 °F. Caution must be taken when planting strawberries in early fall. The lowest temperature recorded under row covers in the winter was about 26 °F, at the time when the temperature outside of the high tunnel was about 4 °F. No crown damage was observed, while flower damage was noticed on varieties that had open blooms in the winter.

The top yielding variety in this trial was Radiance that produced 2.86 lb berries per plant, significantly higher than other varieties. 'San Andreas' (2.37 lb/plant), 'Chandler' (2.17 lb/plant) and 'Benicia' (2.08 lb/plant) also had the marketable yields above 2 lb/plant. 'Camarosa' had the lowest yield (1.42 lb/plant), similar to 'Sweet Ann' (1.62 lb/plant), 'Sweet Charlie' (1.62 lb/plant) and 'Albion' (1.70 lb/plant) (Table 2).

'Albion', 'San Andreas' and 'Sweet Ann' are day-neutral varieties. The harvest of 'Albion' started at the end of September, and the harvest of 'San Andreas' and 'Sweet Ann' started in the middle of October. Fall harvest of the three day-neutral varieties lasted until the end of December. 'Radiance' had the longest harvest period among the varieties although it was marketed as a June-bearing variety. First flower date of 'Radiance' was in middle October, which was similar to 'Sweet Charlie' and later than day-neutral varieties (Table 3). Harvest of 'Radiance' started in November with a few berries harvested during the coldest period in January and February. Primary harvest of 'Radiance' took off in middle April. Among the varieties that had berries ripe in the fall, 'Albion' had numerically higher yield (0.17 lb/plant), but it was not significantly different from the other varieties (Table 4).

Pruning runners in the fall is necessary to ensure plants direct energies to crown development. The variety that produced the most runners was 'Festival'. 'Albion' and 'Camarosa' had the fewest runners (Table 5).

Peak strawberry harvest started in middle April and lasted until the end of May for most of the varieties (Figure 1). 'Sweet Charlie' and 'Benicia' started to harvest in early April, about 10 days earlier than most of the other varieties. 'Sweet Charlie' was primarily harvested in April with fewer berries harvested in May compared with other varieties. Peak harvests of 'Chandler' and 'Camarosa' started in the end of April, about 10 days later than most of the other varieties. Although a few of 'Sweet Ann' were harvested in fall, the peak harvest season of 'Sweet Ann' did not start until the end of April (Figure 1).

Average fruit weight varied significantly among varieties. 'Sweet Ann' had the largest berries, followed by 'Albion' and 'Radiance'. 'Chandler', 'Camarosa' and 'Sweet Charlie' had the smallest berries that weighed significantly less than other varieties. The majority of the varieties

maintained a relatively even berry size throughout the season, but remarkable berry size reduction was observed on 'Benicia' (data not shown). At the peak harvest, 'Festival' and 'Sweet Charlie' had the highest total soluble solids (TSS). They also had higher pH than other varieties. 'San Andreas' had significantly higher titratable acidity. 'Benicia' and 'Camino Real' had the lowest TSS and they were also significantly lower in titratable acidity. Among the varieties, 'San Andreas', 'Festival' and 'Radiance' had firmer flesh than other varieties, while flesh firmness of 'Chandler' was significantly lower than other varieties (Table 6).

Major pests and diseases observed in the season were two-spotted spider mites, powdery mildew, and Botrytis gray mold. Powdery mildew severity rating of 'Benicia' was significantly lower than that of 'Festival' and 'Sweet Charlie' (Table 7). No significant difference in susceptibility to two-spotted spider mites was observed among the varieties (data not shown). Botrytis gray mold was the main cause of unmarketable fruit. 'Sweet Ann' had the most unmarketable fruit compared with other varieties, which accounted for 21.4% of the total yield. 'Festival' had the least amount of unmarketable fruit that accounted for 6.5% of its total yield (Table 2).

Results of the study indicate that growing strawberries in high tunnels in southwest Indiana can achieve a high yield and extend the strawberry season for two months in April and May. The study also shows that it is possible to harvest strawberries in the fall by planting day-neutral varieties in late summer. 'Albion' is the recommended variety for fall harvest. Overall, the recommended varieties for spring harvest based on the one year's study were 'Radiance' 'San Andreas' and 'Festival'. 'Radiance' and 'San Andreas' showed outstanding yields and good fruit quality. 'Festival' produced the sweetest berries in the variety trial and had a moderate yield. 'Radiance' was a superior variety in the current trial, however, it should be noted that 'Radiance' is highly susceptible to crown and root rots, a disease caused by *Phytophthora cactorum* (Whitaker, et al., 2012). Planting 'Radiance' should be avoided if there is a known history of crown and root rots in the soil. 'Benicia' had a high yield potential and was one of the varieties that flowered the earliest. However, young leaves of 'Benicia' showed crinkling and stunted growth, which eventually lead to plant decline during peak harvest season. These symptoms on 'Benicia' was also observed in a trial conducted in North Carolina (Gu, et al., 2017). 'Chandler' is the most widely grown strawberry variety in open field annual plasticulture systems. Although it has a high yield potential, it produced small and soft fruit under high tunnel conditions that largely increased the harvesting time. Comments on individual varieties are presented in Table 8.

Most high tunnels in the Midwest are dedicated to growing tomatoes. Tomato season in high tunnels lasts from late March to November with one or two tomato crops per year in southern Indiana. There is an emerging need for additional crops that will enhance farmers' rotation options to reduce the buildup of diseases and pests in high tunnels, as well as to increase markets for farmers. Annual strawberry production in high tunnels might be a rational option for high tunnel tomato growers as strawberries can be planted after a tomato crop in early September and followed up with another tomato crop in June. In this scenario, two tomato and one strawberry crops can be achieved in a two-year period. However, growers should be aware that tomatoes and strawberries are both susceptible to Verticillium wilt (caused by *Verticillium albo-atrum*). If Verticillium wilt is a concern, strawberries should not be rotated with tomatoes.

Strawberry is a high-value crop. Retail strawberry price can reach $5 per pound during Thanksgiving and Christmas markets. Fall strawberry production has a great economic potential.

However, considering the relatively low yields of day-neutral strawberries in the fall, using vertical systems to increase the number of plants grown in a high tunnel in the fall may be necessary to achieve a profitable margin. Harvests of field-grown strawberries in southern Indian start at the end of May and last to the middle of June. Prices normally range from $2-3.5/lb. Assuming locally produced, high-quality strawberries sell at $3.5/lb during April and early May, the highest yield variety, Radiance, could generate $10 per plant. Around 850-1,000 plants can be planted in a 30’ × 96’ high tunnel with the current planting spacing. A total of $8,500-10,000 could be generated. In addition, having strawberries for sale attracts customers to come and buy other produce. That benefit could outweigh the actual value of selling strawberries.

Growing strawberries is a labor intensive process that require 20-30 labor hours per week during peak harvest season. In addition, strawberries are susceptible to multiple disease and pest damages. Although diseases such as leaf scorch (caused by *Diplocarpon earlianum*) are less likely to occur under high tunnel conditions because of the exclusion of rain, two spotted spider mites can cause severe damage if preventative measures are not taken in a timely manner.

Acknowledgments

Dr. Dan Egel assisted with disease management. Dr. Bruce Bordelon provided technical support. Southwest Purdue Agriculture Center staff Dennis Nowaskie and Angie Thompson assisted with managing the trial and harvesting strawberries. McNitt Growers (Carbondale, IL) donated the strawberry plugs.

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Table 1. Percentages of strawberry plants that died after temperatures in the high tunnel reached 110 °F for about a week in early September, 2016.

Variety	Percentages of dead plants	
Albion	1.5	b[1]
Benicia	21.2	a
Camarosa	10.6	ab
Camino Real	0	b
Chandler	4.5	ab
Festival	0	b
Radiance	4.5	ab
San Andreas	1.5	b
Sweet Ann	15.1	ab
Sweet Charlie	0	b

[1]Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference tests at $P \leq 0.05$.

Table 2. Marketable and cull yields of strawberry varieties grown in a high tunnel in 2015-2016 season in southwest Indiana.

Variety	Marketable yield				Cull			
	Weight *lb/plant*		Fruit number *no./plant*		Weight *lb/plant*		Fruit number *no./plant*	
Albion	1.70	de[1]	31.36	de	0.19	ef	6.41	de
Benicia	2.08	bc	48.14	bc	0.33	bcd	12.14	b
Camarosa	1.42	e	40.82	cd	0.31	bcd	17.23	a
Camino Real	1.89	cd	39.86	cd	0.28	cde	8.59	cd
Chandler	2.17	bc	65.04	a	0.29	cde	13.14	b
Festival	1.88	cd	41.68	c	0.13	f	4.77	e
Radiance	2.86	a	53.36	b	0.39	b	10.73	bc
San Andreas	2.37	b	53.04	b	0.36	bc	12.18	b
Sweet Ann	1.62	de	27.18	e	0.44	a	12.54	b
Sweet Charlie	1.62	de	44.14	bc	0.26	de	11.68	bc

[1]Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference tests at $P \leq 0.05$.

Table 3. First flower date of strawberry varieties grown in a high tunnel in 2015-2016 season in southwest Indiana.

Variety	**First flower date**[1]
Albion	Sep 20
Benicia	Jan 28
Camarosa	Feb 28
Camino Real	Feb 28
Chandler	Mar 6
Festival	Dec 15
Radiance	Oct 16
San Andreas	Sep 24
Sweet Ann	Oct 2
Sweet Charlie	Oct 13

[1.]First flower date was recorded when open blossoms were observed on all the three plots of each variety.

Table 4. Yield of fall harvested strawberry varieties grown in a high tunnel in 2015-2016 season in southwest Indiana.

Variety	**Fall Yield**[1] *lb/plant*	
Albion	0.17	a[2]
Radiance	0.09	a
San Andreas	0.08	a
Sweet Ann	0.10	a
Sweet Charlie	0.09	a

[1.]Strawberries were harvested in Oct. Nov. and Dec.
[2.]Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference tests at $P \leq 0.05$.

Table 5. Runners developed by strawberry varieties grown in a high tunnel in fall 2015 in southwest Indiana.

Variety	**Runners developed in the fall**[1] *no./plant*	
Albion	5.23	e[2]
Benicia	2.68	f
Camarosa	5.27	e
Camino Real	5.73	de
Chandler	9.41	ab
Festival	10.64	a
Radiance	7.68	bcd
San Andreas	5.95	de
Sweet Ann	8.54	abc
Sweet Charlie	7.14	cde

[1.] Runners were pruned weekly till 21 Dec, 2015.

[2.] Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference tests at $P \leq 0.05$.

Table 6. Average fruit weight, total soluble solids, pH, titratable acidity and firmness of strawberries grown in a high tunnel condition in 2015-2016 season in southwest Indiana.

Variety	**Average fruit weight** *gram*		**Total soluble solids** *°Brix*		**pH**		**Titratable acidity** *% citric acid*		**Firmness** *gram-force*	
Albion	24.61	ab[1]	5.42	cde	3.77	c	0.58	bc	334.00	de
Benicia	19.86	d	4.80	e	3.81	bc	0.50	d	383.33	bcd
Camarosa	16.00	e	6.40	ab	3.92	abc	0.58	bc	346.00	de
Camino Real	21.64	cd	4.90	e	3.98	ab	0.48	d	370.00	cd
Chandler	15.23	e	6.05	bc	3.86	abc	0.63	ab	234.00	f
Festival	20.38	d	6.82	a	4.01	a	0.58	bc	430.67	ab
Radiance	24.35	bc	5.05	de	3.88	abc	0.52	cd	410.00	abc
San Andreas	20.41	d	5.72	bcd	3.75	c	0.67	a	455.33	a
Sweet Ann	27.43	a	5.77	bcd	3.86	abc	0.58	bc	398.67	bc
Sweet Charlie	16.67	e	6.92	a	4.01	a	0.55	cd	315.33	e

[1]Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference tests at $P \leq 0.05$.

Table 7. Severity rating of powdery mildew of strawberries grown in a high tunnel in 2015-2016 season in southwest Indiana.

Variety	Disease severity[1]	
Albion	3.09	abc
Benicia	2.38	c
Camarosa	3.48	abc
Camino Real	3.05	abc
Chandler	2.95	bc
Festival	4.19	a
Radiance	2.62	bc
San Andreas	2.71	bc
Sweet Ann	2.86	bc
Sweet Charlie	3.62	ab

[1].Horsfall-barratt scale (0. 0% severity; 1. 0-3% severity; 2. 3-6% severity; 3. 6-12% severity; 4. 12-25% severity; 5. 25-50% severity; 6. 50-75% severity; 7. 75-88% severity; 8. 88-94% severity; 9. 94-97% severity; 10. 97-100% severity; 11. 100% severity) was used for assessing powdery mildew damage on 6 plants in each experimental plot. Ratings of the 6 plants were averaged for statistical analyses. Disease severity was rated on Oct. 28, 2015.

Table 8. Comments on strawberry varieties grown in a high tunnel in 2015-2016 season in southwest Indiana.

Variety	Comments
Albion	Suitable for commercial fall harvest in high tunnels, peak harvest in the spring start in middle April, large fruit size, total yield was moderate to low
Benicia	Peak harvest started in early April. High yield potential. Good for the early market. Relatively tolerant to powdery mildew. Plant decline in peak harvest
Camarosa	Peak harvest start in end April, low yield potential, small berries
Camino Real	Peak harvest start in middle April, moderate yield potential
Chandler	Peak harvest start in end April, high yield potential, small and soft berries
Festival	Peak harvest start in middle of April, moderate yield potential, high fruit quality, produce many runners, relatively more resistant to gray mold but more susceptible to powdery mildew
Radiance	Harvest start in the fall, very high yield potential, longest harvest season
San Andreas	Harvest start in the fall, peak harvest start in middle April, high yield potential
Sweet Ann	Harvest start in the fall, peak harvest start in end April, low yield potential, large berry size, relatively more susceptible to gray mold
Sweet Charlie	Peak harvest start in early April, low yield potential, good fruit quality but small berry size

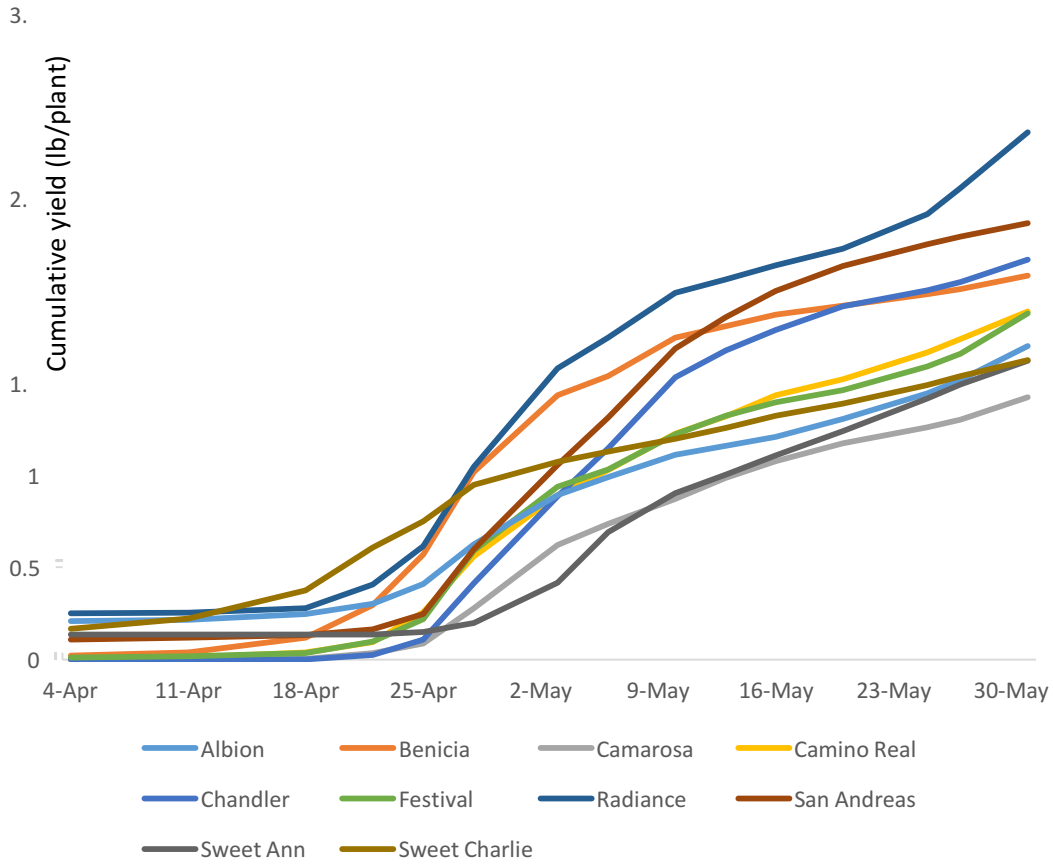

Figure 1. Yield in April and May of strawberry varieties grown in a high tunnel condition in 2015-2016 season in southwest Indiana.