Strawberry Production in an Elevated Bench Growing System inside a High Tunnel in Southern Indiana

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Introduction

Locally produced strawberries have excellent market potential. Farmers are exploring different systems for growing strawberries in Indiana. Compared to open-field production, protected culture extends the production season and reduces the risk of unpredictable and deteriorating weather. Greenhouse production is attractive, but the high initial cost of building greenhouses with advanced environmental control is prohibitive to most small-scale farmers. High tunnels are a low-cost, plastic-covered structure that provides an intermediate level of environmental protection and control. Growing strawberries in-ground inside a high tunnel can extend the early-season harvest, increase yield, and reduce production risks compared to open-field production in the region. However, in-ground production is limited by poor soil quality and the potential build-up of soilborne diseases. Soils inside high tunnels, especially those in tomato production for multiple years, tend to build up salt and have high pH, which is unsuitable for strawberry production. Substrate production overcomes these soil challenges. Additionally, it makes growing strawberries on an elevated system possible, which improves harvesting efficiency and reduces physical strain on farm workers.

Objective of this study is to evaluate the performance of eight strawberry cultivars grown in an elevated bench system. Yield and quality parameters were measured. This report also includes a discussion on production challenges and economic considerations of this production system.

Materials and Methods

A commercial strawberry growing system (IBEX Growing Systems, Fort Wayne, IN) was used in the study. We built the system inside a high tunnel at Southwest Purdue Agricultural Center in Vincennes, IN in fall 2021. The system has eight wires across frames installed into the ground every 8-feet. Strawberries were grown in 1-gallon black fabric bags placed between the two wires. Plant spacing is 1’ apart. A total of 376 bags can fit into a 102’ long bench system. The bags were filled with peat-based growing medium (Pro Mix HP Soilless Potting Mix). One drip stake assembly with a 0.5 GPH emitter was placed in each bag (Fig.1).

Fig.1. Strawberries were grown in 1-gallon black fabric bags. Each bag has an irrigation stake.

Eight strawberry cultivars (McNitt Growers, Carbondale, IL) were evaluated in this study, including three day-neutral cultivars ‘Albion, ‘San Andreas’ and ‘Monterey’, three short-day cultivars recently released from the University of Florida ‘Florida Radiance’, ‘Florida Sensation’, ‘Florida Brilliance’ and two relatively older short-day cultivars widely grown on plasticulture in North Carolina ‘Chandler’ and ‘Sweet Charlie’.

Strawberry plugs were planted on 20 Sep. 2021, one plant per bag. The experimental design was a completely randomized block design with three blocks. Each experimental unit included 12 plants.

Plants were irrigated twice daily most of the season, each irrigation event lasted about 3 minutes except for the event intended to leach excessive salts. Nutrients were applied at each irrigation event except in the first two weeks after transplanting. A complete fertilizer $25N\text{-}9P_2O\text{-}17K_2O$ (Jack’s 25-9-17 Berry Special, Allentown, PA) plus micronutrients was used. The nutrient solution had 100 ppm N in the fall and early spring and reduced to 70 ppm N during fruit ripening.

Alkalinity of the irrigation water was 130 mg/L, and the pH was 7.4 (Irrigation Water Analysis. A&L Greak Lakes Laboratories, Fort Wayne, IN). Electric conductivity (EC) and pH of medium runoff were monitored throughout the season. Sulfuric acid 93% (Water Solutions Unlimited, Camby, IN) was added to the irrigation system and reduced the irrigation water pH to 6.5 at end of Feb. The irrigation water pH was further reduced to 5.5 in Apr. The tool ALKCALC (University of New Hampshire) was used to calculate the acid amount.

Strawberries were harvested at the fully ripe stage. Fruit number and weight from each experimental plot were recorded. Harvest was conducted once a week from 15 Oct. to end of Nov. 2021, and then every two weeks until 3 Jan. 2022. Spring harvest began on 14 Apr and lasted until 10 June. Fruits were harvested twice a week in the spring. Fruit weight and number of each experimental plot were recorded. Severely mishappened fruit, and disease and insect damaged fruit were separated as unmarketable.

Bags were placed on the ground inside of the high tunnel and covered with a 1.5-oz thickness floating row cover in the winter (5 Jan. to 22 Feb.2022) (Fig. 2). The bags were overhead irrigated once in the winter. Dead leaves and flowers were pruned down to the crown before bags were moved back onto the bench system in the spring.

Fig.2. The growing bags were placed on the ground inside the high tunnel and covered with a floating row cover in the winter (left). Plants were pruned close to the crown before bags were moved back onto the bench system (right)

About 1000 predatory mites (*Phytoseiulus persimilis* PLUS, Arbico organics, Oro Valley, AZ) were evenly sprinkled on the plants of the bench system on 3 May, 2022 to suppress twospotted spider mites (TSSM). Predatory mites, TSSM, and aphids were counted on five randomly selected trifoliate leaves of each experimental plot a week after the predatory mite's release. Powdery mildew disease symptom was rated using a Horsfall-Barratt rating scale (1 = 0% disease severity; 2 = 0% to 3% disease severity; 3 = 3% to 6% disease severity; 4 = 6% to12% disease severity; 5 = 12% to 25% disease severity; 6 = 25% to 50% disease severity; 7 = 50% to 75% disease severity; 8 = 75% to 88% disease severity; 9 = 88% to 94% disease severity; 10 = 94% to 97% disease severity; 11 = 97% to 100% disease severity; 12 = 100% disease severity) before plants were wintered on the ground.

During peak harvest, three representative fruits of each experimental plot were selected to measure fruit weight, total soluble solids and firmness. A digital refractometer (Atago 3810; Cole-Parmer North America, Vernon Hills, IL, USA) was used to measure the total soluble solids of juice extracted from each fruit. A hand-held penetrometer (FDK32 Force Dial; Wagner Instruments, Greenwich, CT, USA) with a 7-mm tip was used to measure flesh firmness at the shoulder of each fruit.

Data were analyzed using analysis of variance (ANOVA) (JMP Pro 16; SAS Institute Inc., Cary, NC, USA). Differences among means were tested by Fisher's protected least significant difference at $\alpha = 0.05$.

Results

Temperature. Daily average, maximal and minimal temperatures recorded at the plant canopy are presented in Fig. 3. Average temperatures were between 60 to 80 °F in the first month after transplanting and stayed between 40 to 60 °F afterward before plants were placed on the ground. During the period when plants were covered with floating row covers on the ground, the average temperatures at the plant canopy were between 30 to 50 °F. The lowest recorded temperature at plant canopy was 14 °F on 5 Feb. The average canopy temperature was around 50 °F when plants were placed back onto the bench system and increased to above 70 °F around the middle of May.

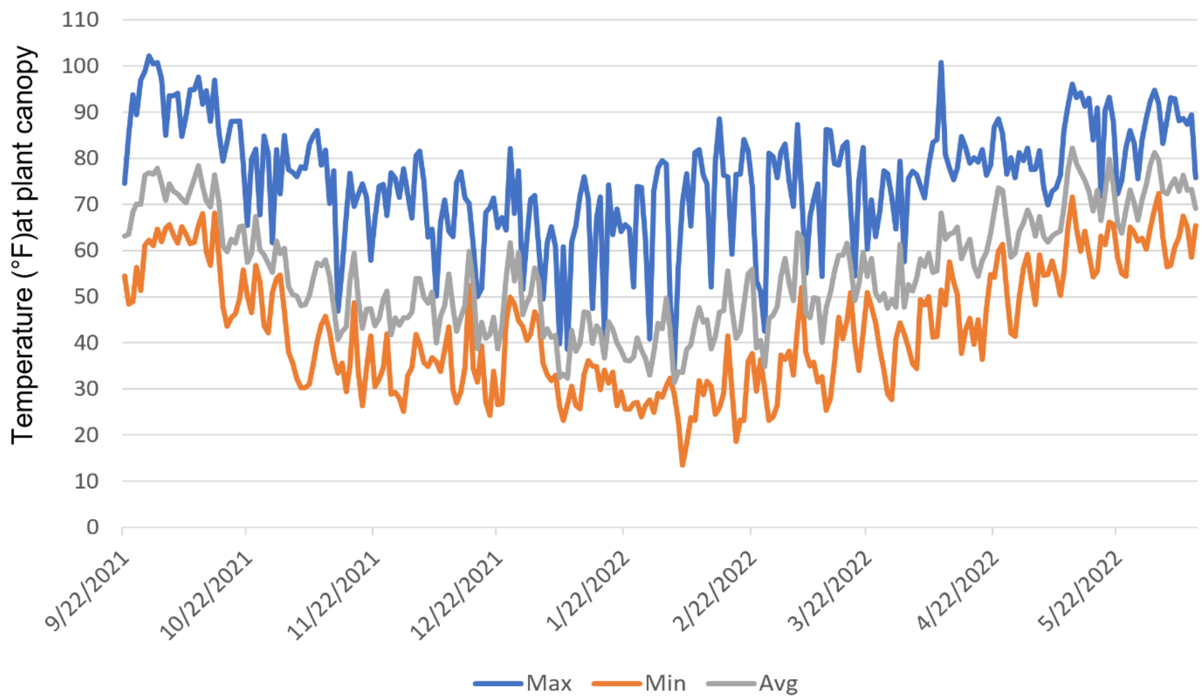

Fig. 3. Daily average, maximal and minimal temperatures recorded at the plant canopy of strawberries grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Yield. In the production period from 20 Sep. 2021 to 10 June 2022, the marketable yield of evaluated cultivars ranged from 0.6 to 1.15 lb/plant. The top-yielding cultivar was Florida Radiance (1.15 lb/plant), followed by San Andreas (1.09 lb/plant) and Florida Sensation (0.94 lb/plant). The lowest-yielding cultivar was Albion (0.6 lb/plant) (Table 1). Over 90% of total yields were marketable. Cultivars Monterey had ripened fruit the earliest among all the cultivars. The first harvest was about a month after planting. Day-neutral cultivars and low-chilling short-day cultivars had ripened fruit in the fall. The fall yields, however, were less than 10% of the spring yields except for 'Monterey'. 'Sweet Charlie' and 'Florida Radiance' started to produce fruit the earliest in the spring, around the middle of April. We ended spring harvest on

10 June was because of high temperatures. At the end of spring harvest, 'Albion' had the most unripened fruit.

Table 1. Fall and whole-season yields of strawberry cultivars grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Cultivar	Fall Yield				Whole-season Yield			
	Weight (lb/plant)		Fruit No. per plant		Weight (lb/plant)		Fruit No. per plant	
Florida Radiance	0.03	c	0.61	cd	1.15	a	40.3	ab
San Andreas	0.06	abc	1.8	b	1.09	ab	37.4	bc
Florida Sensation	0.08	a	1.5	bc	0.94	abc	28.5	de
Monterey	0.09	a	3.36	a	0.91	bcd	27.5	e
Chandler	0	d	0	d	0.82	cd	45.5	a
Sweet Charlie	0	d	0	d	0.77	cde	33.4	de
Florida Brilliance	0.07	ab	1.5	bc	0.71	de	26.2	e
Albion	0.05	bc	1.34	bc	0.60	e	18.7	e
P-value	<0.0001		<0.0001		0.0008		<0.0001	

Fruit quality. Among the evaluated cultivars, 'Chandler' and 'Monterey' had the highest total soluble solids, while 'Florida Radiance' and 'Florida Sensation' had the lowest soluble solids. 'Chandler' and 'Sweet Charlie' had the lowest values on fruit firmness and their fruit sizes were among the smallest (Table 2).

Table 2. Fruit weight, total soluble solids and flesh firmness of strawberry cultivars grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Cultivar	Fruit weight (g)		Total soluble solids (%)		Firmness (grams-force)	
Florida Radiance	20.89	abc	4.42	c	766.9	a
San Andreas	24.78	ab	5.95	b	595.4	ab
Florida Sensation	26.22	a	4.39	c	589.1	ab
Monterey	24.00	ab	6.93	ab	494.4	bc
Chandler	16.00	c	7.87	a	330.0	c
Sweet Charlie	17.11	c	6.22	b	322.9	c
Florida Brilliance	18.33	c	5.50	bc	512.6	abc
Albion	20.11	bc	6.20	b	483.4	bc
P-value	0.0095		0.0029		0.0403	

Plant Health. Interveinal chlorosis (Fig.4) was observed toward the end of Mar. The symptom was most pronounced in 'Chandler'. Comparing leaf chlorophyll contents, 'Chandler' had the lowest values and 'Florida Sensation' and 'San Andreas' had the highest values (Table 3).

Analyzing individual nutrient contents of leaf samples revealed Copper, Ion, and Zinc levels were the lowest on 'Chandler' (Waters Agricultural Laboratories, Inc. Owensboro, KY). The nutrient disorder was likely caused by elevated growing medium pH that increased from 6.9 to 7.8 by the end of Mar (data not shown). The interveinal chlorosis symptom gradually recovered in Apr. after adjusting the irrigation water pH to 5.5. The nutrient disorder may have negatively affected strawberry yield, particularly for 'Chandler'.

Fig. 4. A 'Chandler' plant leaves showed interveinal chlorosis symptom as growing medium pH increased in the season.

Table 3. Leaf chlorophyll content of strawberry cultivars grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Cultivar	Leaf chlorophyll content (CCI)	
Florida Sensation	19.42	a
San Andreas	19.27	a
Florida Radiance	18.38	ab
Florida Brilliance	17.51	ab
Albion	17.43	ab
Monterey	16.22	abc
Sweet Charlie	14.31	bc
Chandler	11.63	c
P-value	<0.0001	

Diseases and Insect Pests. Cultivar Florida Brilliance started to show a decline in Nov. *Neopestalotiopsis* sp. was isolated from the declined plants (Fig.5). Those plants did not survive the winter and were excluded from the remaining data collection. About 25% of 'Florida Brilliance' plants showed the symptom.

Powdery mildew (*Podosphaera aphanis*) occurred in fall of 2022. The symptoms were observed on leaves, runners and fruit. 'Monterey' had the highest disease rating (Table 4). The symptom was not observed on ‘Florida Brilliance’ and ‘Chandler’ at the time when the disease was rated. White mold (*Sclerotinia* spp.) was observed in the winter. The damaged tissues were cleaned before plant regrowth in the spring. No additional damage was observed in the spring. Gray mold (*Botrytis cinerea*) affected a few fruits lying on the growing medium. Gray mold pressure in general was low in the trial.

Fig. 5. A declined plant of cultivar Florida Brilliance. The photo was taken on 6 Dec. 2021.

Table 4. Powdery mildew rating of strawberry cultivars grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Cultivar	Powdery Mildew symptom rating[z]	
Monterey	4.67	a
Florida Sensation	2.67	b
Albion	2.00	bc
Florida Radiance	2.00	bc
Sweet Charlie	1.33	cd
San Andrea	0.67	de
Florida Brilliance	0	e
Chandler	0	e
P-value	<0.0001	

[z.] The disease symptom was rated on 3 Jan. 2022 using a Horsfall-Barratt scale.

Fungus gnats caused damage on ripening strawberry fruit when the fruits directly contacted the growing medium (Fig. 6). Aphids and twospotted spider mites (TSSM) were major pest problems in the spring. The numbers of TSSM, predatory mites (*Phytoseiulus persimilis*), and aphids were counted on the leaves of each cultivar. The number of TSSM and aphids were not significantly different among cultivars (Table 5). Numerically, cultivar Florida Sensation had the most TSSM, and the most predatory mites.

Fig. 6. Fungus gnats caused damage on ripening strawberry fruit when the fruits directly contacted the growing medium

Table 5. Twospotted spider mites, *Phytoseiulus persimilis* predatory mites and aphids on each leaf of strawberry cultivars grown on an elevated bench system inside a high tunnel in Vincennes, IN in the 2021-2022 season.

Cultivar	Twospotted spider mites	*Phytoseiulus persimilis*[z]		Aphids
Florida Radiance	26.9	2.33	b	2.3
San Andrea	59.7	2.00	b	10.3
Florida Sensation	96.7	11.3	a	6.9
Monterey	25.8	3.47	b	11.4
Chandler	19.3	1.00	b	2.0
Sweet Charlie	9.3	0.9	b	5.5
Florida Brilliance	81.4	2.69	b	7.7
Albion	73.1	5.33	b	12.0
P-value	0.0787	0.033		0.0768

[z.] Leaf samples were collected on 10 May 2022, a week after *P. persimilis* release.

Conclusion

The bench growing system has advantages over in-ground production because it improves harvest efficiency, overcomes the challenges of poor soil quality, and avoids the buildup of soilborne diseases.

Economic feasibility, however, is the main barrier to adapting the system. The cost of irrigation stakes, growing medium, fabric bags, fertilizers, and strawberry plugs used in the study was estimated at $1,843 (Table 6). This cost does not include the bench itself, the cost of fertilizer injector and controller etc. Reusing drip stakes and grow bags for multiple seasons can reduce the cost, but strict sanitation practices must be followed to ensure pathogens free of the materials used for the following seasons.

Table 6. Partial variable costs of a 100’ bench system (400 plants total)

Item	Quantity	$/Unit	Total ($)
Assembled drip stakes	400	1.85	740
One- gallon fabric grow bag	400	1.58	632
Pro Mix HP Soilless potting mix 38 cu. ft.	8	37	296
Jack’s 25-9-17 Berry Special fertilizer (25lb)	0.5	70	35
Strawberry Plugs	400	0.35	140
Total			1843

Strawberry yield in this experiment ranged from 0.6 to 1.15 lb/plant depending on the cultivars. Better management of root zone pH and disease and insect pests might achieve a higher yield. The primary production season in this study was between the middle of April and early June, similar to the main yield duration of in-ground high tunnel production in our previous studies.

The system is more likely to work economically if yields in the fall season can be improved. Among the evaluated cultivars, day-neutral cultivar ‘Monterey’ had ripened berries about a month after planting and yielded 0.09 lb/plant in the fall. Future studies are warranted to evaluate the fall yield potential of this cultivar when plugs were planted at the end of Aug. or using bare-root plants and planted in the summer.

The Harvest in this study ended on 10 June 2022 because of high temperatures inside the high tunnel. Cultivar ‘Albion’ had the most flowers and unripened fruit at the final harvest. Harvest of ‘Albion’ may continue if shade cloth is used for the high tunnel. It is also possible to continue the harvest of day-neutral cultivars into the 2022 fall season. This practice was shown a success in northern Indiana. Plants were pruned to the crown at the end of the spring harvest, leaves regrew in the summer. Plants bloomed and harvest started again in the fall. However, summer management, especially for twospotted spider mites will be more challenging if harvests continue into the fall season. Other pests, including tarnished plant bug, may also be more challenging in the fall as pest populations build. A well-developed biological control approach for these pests is critical to ensure the system’s success. Future studies are warranted to evaluate the yield potential of the extended harvest of day-neutral cultivars in the high tunnel system.

Cultivar Florida Radiance, San Andreas and Florida Sensation had the highest yield during the production period. However, fruit of the three cultivars tend to have low sugar content and greater firmness values. These strawberries may be less preferred at the local market. Among the three day-neutral cultivars, Monterey and San Andreas has similar yields, and they both yielded higher than that of Albion during the production period. ‘Monterey’ had good fruit quality and produced berries the earliest in the fall. However, we found ‘Monterey’ was particularly susceptible to powdery mildew. An improved powdery mildew management approach must be developed to grow this cultivar successfully. Cultivar ‘Chandler’ is widely grown for open-field plasticulture production. This cultivar seems particularly susceptible to nutrient disorder when medium pH is above the optimal range. ‘Chandler’ may not be a suitable cultivar for the substrate production system.

Acknowledgment:

We appreciate Dr. Petrus Langenhoven, Dr. Chieri Kubota and Mark Kroggel for the technical support of system management. We appreciate Richard Barnes reviewing this manuscript and providing comments. We appreciate Dennis Nowaskie and other Southwest Purdue Ag Center crew helping with high tunnel management.

This material is based upon work supported by the USDA National Institute of Food and Agriculture under award number 2021-38640-34714 through the North Central Region SARE program under project number LNC21-454. This work is also supported in part by the Specialty Crop Research Initiative (SCRI) [grant no. 2021-51181-35858/project accession no. 1027430] from the USDA National Institute of Food and Agriculture.