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Low Cost High Tunnel versus Open Field Production of Organically Grown Strawberries in North Florida: A Three-year Evaluation

Alex Bolques[1]*, Gilbert Queeley[2], Fanny Ospina[1], and Vonda Richardson[2]

[1]Florida A&M University, Research and Extension Center, 4259 Bainbridge Highway, Quincy, FL 32352

[2]Florida A&M University, Cooperative Extension Programs, 215 Perry Paige, Bldg. South., Tallahassee, FL 32307

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In north Florida, crop production can be limited by freezing temperatures during winter months and as such, many fresh market, organic and small scale producers utilize season extension techniques to protect specialty crops from damage. Low cost high tunnels (LCHT) are temporary crop protective structures that can be easily constructed in the field to protect crops from adverse weather conditions and pests. They are naturally heated and ventilated by roll-up sides as a means of controlling environmental conditions inside the tunnel. In this study, we present the results of a 3-year evaluation of strawberries grown in a LCHT versus open field (OF) treatment. The objective was to determine whether the LCHT provided any agronomic benefits, relative to fruit yield, over the OF. Four strawberry (*Fragaria ×ananassa*) cultivars [Sensation™, ('Florida 127'), 'Florida Brilliance', 'Florida Radiance', and 'Florida Beauty'] were grown in each production system. Experimental plots consisted of 16 subplots each containing 16 strawberry plants per cultivar in a randomized complete block design with four replications. Yield data were collected weekly during the 2016/17, 2017/18, and 2019/20 Fall through Spring growing seasons. Descriptive statistics were generated using SAS ver. 9.4. The three-year average yield from the LCHT and OF treatments were 1744 lb/acre and 949 lb/acre, respectively. An independent samples *t* test was used to compare treatment means. The yield obtained from the LCHT was significantly higher ($P < 0.001$). The study concluded that the LCHT is a sustainable alternative to OF production of strawberries in north Florida.

For the past four winter seasons in north Florida (excluding the 2018-19 strawberry season due to damaged caused by Hurricane Michael), low cost high tunnel (LCHT) production of organically grown strawberries has been evaluated against the risk of winter injury or damage to strawberry plants, flowers, and fruit. This damage can occur when ambient air temperatures fall below 32 °F (0 °C). To determine whether a LCHT can provide any agronomic benefits, including fruit yield, strawberry production inside the LCHT were compared to fruit production in an open field (OF). This comparative study also served as an extension outreach demonstration to validate the feasibility of growing strawberries for small-scale production.

In the first year of the study, Oct. 2016 to Apr. 2017, it was determined that the risk of winter injury or damage could reduce marketable fruit yield thereby reducing crop profitability (Bolques et al., 2018). The study was repeated for a second year during the Oct. 2017 to Apr. 2018 strawberry season. In this paper, we discuss the results of a low cost high tunnel structure versus open field production of organically grown strawberries in North Florida during the third and final year.

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*Corresponding author. Email: alejandro.bolques@famu.edu

Materials and Methods

Experimental Design. This study was conducted at the Florida A&M University, Research and Extension Center in Quincy, FL, and covers three strawberry growing seasons. For the first season, Oct. 2016 to Apr. 2017, four strawberry cultivars [Sensation™ (Florida 127) (Whitaker et al, 2014), Winterstar™ (FL 05-107) (Whitaker et al., 2012), 'Florida Radiance', and 'Strawberry Festival'] were evaluated for their performance in two 12 ft (3.6 m) wide × 100 ft (30 m) low cost high tunnels and one 12 ft (3.6 m) wide × 100 ft (30 m) open field arrangements. Likewise, for the 2017–2018 growing season, LCHT and OF strawberry cultivars were the same with the exception of 'Strawberry Festival' which was replaced by 'Florida Beauty'. For the final year, 2019–2020, LCHT and OF strawberry cultivars were the same with the exception of Winterstar™, which was replaced by 'Florida Brilliance'. The objectives, methods and data analytical procedures were the same as those utilized in years 1 and year 2 studies (Bolques et al., 2018 and Bolques et al., 2019).

The soil at the study site is an Orangeburg loamy sand with moderate permeability and water holding capacity (USDANRCS, 2017). Soil preparation consisted of growing a sunn hemp cover crop, *Crotalaria juncea*, during the late summer (Aug.–Sept.). The cover crop was selected for its ability to fix nitrogen and when incorporated into the soil, can release allelopathic compounds

toxic to plant parasitic nematodes (Wang, 2008). Following cover crop incorporation, 5 lb (2.3 kg) of preplant fertilizer, Nature Safe 8–3–5 Super Fine organic fertilizer, incorporated into the soil for each production bed prior to forming the plastic mulch raised beds, which also included two 5/8 inch (1.6 cm) T-Tape drip irrigation lines per bed. Two rows were designated for the OF treatment and four for the LCHT. Commercially available strawberry plant plugs were used for the evaluations and were planted using a randomized complete block design with 4 replications. Each treatment consisted of four 50-ft (15 m) subplots. Each subplot contained four strawberry cultivars with 16 plants per cultivar. The planting arrangement throughout the experimental plots consisted of double rows spaced 18 inches (45) cm × 18 inches (45) cm apart. At the end of each experimental plot, four strawberry plugs were planted as end of row buffers.

The crop was irrigated daily for an hour the first week, then three times per week or as needed. At mid-season (January), individual plants were top dressed with a teaspoon of Nature Safe 8–3–5 Super Fine organic fertilizer every three weeks. The crop was scouted weekly and applied control measures were recorded. Ripe (red) fruits were sampled weekly from eight plants in each experimental subplot. Fruit yield and marketable yield were measured by weight.

Low cost high tunnel. The LCHT was constructed based on design specifications by Coolong (2012) with modifications to the structure anchoring (Bolques et al., 2016). Otherwise, LCHT construction was the same as Bolques et al. (2018 and 2019). A "how to video" file on how to construct a LCHT is available on YouTube (Bolques, 2017). Only 1 LCHT was evaluated during the third year which included structural improvements to the hoop assembly, anchor system, and rope tie down.

Hoop structural improvements. The major structural component of the LCHT was the use of 1 in (2.5 cm) in diameter by 20 ft (6 m) long polyvinyl chloride (PVC) pipe to form a hoop segment. The 1 in × 20 ft PVC pipe used to make a hoop section was replaced by two galvanized steel chain link fence top rails, each measuring 1 3/8 in (42 cm) × 10.5 ft (3.2 m). A DY12-B hoop bender (Lost Greek Greenhouses, LLC, Mineola, TX), was used to bend the metal pipes. Two bent metal hoop sections inserted at the belled end and held together by a Tek screw, completed a metal hoop section.

Anchor structural improvements. Upgrading from PVC to metal hoops also meant upgrading the anchoring system. As a result of the belled end design of the metal hoop pipe, 2 different anchors was needed for each metal hoop section: a 2 ft, 1 3/8-in galvanized steel chain link fence top rail and a 2 ft, 11-in metallic electrical conduit. Both were installed 18 in. into the ground leaving 6 in exposed above ground. The belled end of the metal hoop was installed into the 1 3/8-in anchor and the non-belled end was installed over the 1-in anchor.

Rope assembly improvements. A braided nylon rope was used to hold the tunnel poly plastic in place over the hoop sections. At the metal hoop and anchor insert points, a 3/4-in, two-hole metal strap was mounted using 5/16 hex screws making a strong joint between the hoop and the anchor.

Results and Discussions

The results from the three-year evaluation are shown in Tables 1, 2, and 3, respectively. In each table the treatment means compared are the mean yields of the cultivars within each production

Table 1. Mean yield (lb/acre) of four organically grown strawberry cultivars from open field and low cost high tunnel production, Fall 2016–Spring 2017 in north Florida.

Treatment	Cultivar	Min	Max	Mean[z]	±SD
Open field	Strawberry Festival	0.00	5101.4	1326.4 a	1333.81
	Florida Radiance	0.00	3464.3	524.1 b	551.1
	Winterstar™	0.00	6463.1	1682.2 a	1617.1
	Sensation	0.00	6099.6	1361.8 a	1391.8
Low cost high tunnel	Strawberry Festival	232.7	8623.1	3426.1 a	2142.4
	Florida Radiance	67.3	6151.1	1640.2 c	1226.6
	Winterstar™	0.00	7013.7	2598.5 b	1750.3
	Sensation	0.00	10164.1	2835.1 b	1623.8

[z]Means within each production system with the same letter are not significantly different at $\alpha = 0.05$.

Table 2. Mean yield (lb/acre) of four organically grown strawberry cultivars from open field and low cost high tunnel production, Fall 2017–Spring 2018 in North Florida.

Treatment	Cultivar	Min	Max	Mean[z]	±SD
Open field	Florida Beauty	0.00	3575.2	776.9 b	957.0
	Florida Radiance	0.00	9267.8	1810.3 a	1993.5
	Winterstar™	0.00	4669.6	1108.9 b	1139.9
	Sensation	0.00	5400.4	1224.2 ab	1419.61
Low cost high tunnel	Florida Beauty	0.00	4888.4	922.3 b	788.0
	Florida Radiance	57.4	4866.6	1504.7 a	804.7
	Winterstar™	107.0	4628.0	1437.7 a	996.3
	Sensation	0.00	4595.3	1232.8 a	919.6

[z]Means within each production system with the same letter are not significantly different at $\alpha = 0.05$.

Table 3. Mean yield (lb/ac) of four organically grown strawberry cultivars from open field and low cost high tunnel production, Fall 2019–Spring 2020 in north Florida.

Treatment	Cultivar	Min	Max	Mean[z]	±SD
Open field	Florida Beauty	0.00	3179.1	477.8 a	680.6
	Florida Radiance	0.00	3426.7	606.8 a	794.9
	Florida Brilliance	0.00	2456.1	456.6 a	555.0
	Sensation	0.00	3575.2	543.7 a	682.7
Low cost high tunnel	Florida Beauty	0.00	4318.0	812.4 a	957.14
	Florida Radiance	0.00	6199.7	1565.9 ab	1473.5
	Florida Brilliance	0.00	6784.0	1290.1 ab	1309.1
	Sensation	0.00	5357.9	1232.2 b	1165.8

[z]Means within each production system with the same letter are not significantly different at $\alpha = 0.05$.

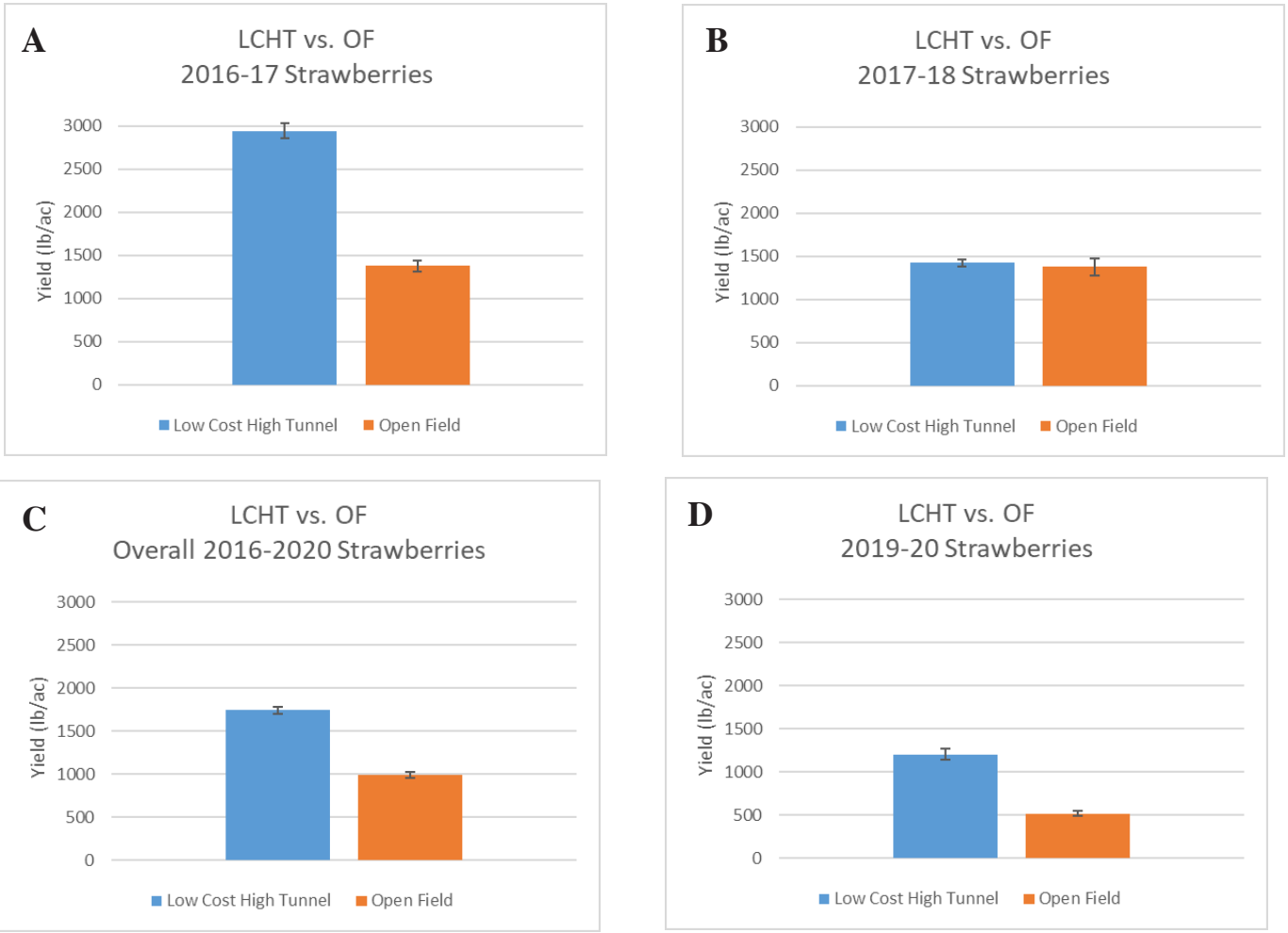

Fig. 1. Mean yield (lb/acre) of four organically grown strawberry cultivars in north Florida by season (Oct.–Apr.) in a low cost high tunnel versus open field (**A–C**) and overall strawberry production for all three seasons, excluding the 2018–19 season (**D**).

system. The yield (lb/acre) comparisons of the two production systems (OF vs. LCHT) are depicted in Fig. 1. This comparison allows for a visual determination of whether the LCHT provided any yield advantages over the OF (control).

Evaluation of strawberry cultivars in the OF and LCHT (2016–17). In the OF, mean yield ranged from 524 lb/acre (587 kg/ha) for 'Florida Radiance' to 1682 lb/acre (1885 kg/ha) for Florida brilliance. For the 2016 growing season, 'Florida Radiance' produced significantly lower yield compared to the other 3 cultivars (Table 1). Winterstar™ was notably the highest producer in the OF. However, when compared to 'Strawberry Festival' and 'Sensation™', its yield was not significantly higher than these two cultivars (Table 1).

In the LCHT, mean yield ranged from 1640 lb/acre (1838 kg/ha) for 'Florida Radiance' to 3426 lb/acre (3840 kg/ha) for 'Strawberry Festival'. The yield from 'Florida Radiance' was significantly lower compared to the other 3 cultivars (Table 1). 'Strawberry Festival' produced significantly higher yield compared to the other cultivars in the LCHT. There were no significant differences between the yield from Winterstar™ and Sensation™.

Evaluation of strawberry cultivars in the OF and LCHT (2017–18). The mean yield in the OF ranged from 777 lb/acre (871 kg/ha) for 'Florida Beauty' to 1810 lb/acre (2029 kg/ha) for 'Florida Radiance'. Mean yield from 'Florida Radiance' in the OF was significantly higher than for the other three cultivars. The yields for 'Florida Beauty', Winterstar™, and Sensation™, were not significantly different (Table 2).

In the LCHT, mean yield ranged from 922 lb/acre (1033 kg/ha) ('Florida Beauty') to 1504 lb/acre (1686 kg/ha) ('Florida Radiance'). The yield obtained from 'Florida Beauty' in the LCHT was significantly lower compared to the other 3 cultivars. The yields obtained from 'Florida Radiance', Winterstar™ and Sensation™ were not significantly different (Table 2). In 2017, 'Florida Radiance' was the best overall performer in both the OF and the LCHT (Table 2).

Evaluation of strawberry cultivars in the OF (2019–20). The mean yield in the OF ranged from 456 lb/acre (511 kg/ha) for 'Florida Brilliance' to 607 lb/acre (680 kg/ha) for 'Florida Radiance'. Mean yield from 'Florida Radiance' in the OF was higher than the other 3 cultivars but there were no significantly differences among them (Table 3).

In the LCHT, mean yield ranged from 812 lb/acre (910 kg/ha) for 'Florida Beauty' to 1565 lb/acre (1755 kg/ha) for 'Florida Radiance'. The yield obtained from 'Florida Beauty' in the LCHT was significantly lower than the other 3 cultivars. The yields obtained from 'Florida Radiance' was numerically higher than, but not significantly different from 'Florida Brilliance' and Sensation™ (Table 3).

Across the three-year evaluation beginning with the 2016–17 growing season, the best yield performances were observed for

Winterstar™ in the OF and 'Strawberry Festival' in the LCHT. For the 2017–18 growing season, 'Florida Radiance' performed best in both the OF and the LCHT. In 2019–20, 'Florida Radiance' also performed better in the OF and in the LCHT (Table 4 and Table 5, respectively).

Evaluating the of vs. LCHT. Total strawberry yields by production system was used to help determine the feasibility of growing in a low cost high tunnel vs. open field for small-scale strawberry production in north Florida. Temperatures below 30 °F (–1 °C) can be a common occurrence during the fall and winter months. While strawberry plants can tolerate temperatures near 22 °F (–6 °C) before serious damage to the plant crown occurs, many growers use frost blankets, row covers and latent heat from overhead irrigation to protect the crop from freezes. With the popularity and convenience of growing under cover, many small-scale farmers have begun to grow crops in high tunnels mainly because they provide a layer of protection against frost. A common high tunnel management practice is the closing or rolling down of poly plastic curtains and entry ways. The low cost high tunnel evaluated has pull down sides along both sides of the structure to help insulate the crop against freeze and when pulled-up it acts to ventilate the interior of the structure.

It was observed that during the 2016–17 season there were two major freeze events where temperatures dropped as low as 23 °F (–5 °C). In 2017–18, there were five events reaching as low as 19 °F (–7 °C) and for the 2019–20 season there were three events where temperatures dropped to 26 °F (–3 °C). We believe that the 2017–18 freezing events may have caused plant growth to slow down considerably (Fig. 1). In this case, we conclude that the LCHT did not provide any statistically significant yield advantage over the OF. It must be mentioned however, that the LCHT provided other benefits such as: protection from frost, insect and disease management thereby improving plant health and quality of fruit. However, small-scale and limited resource farmers will still have to balance the additional cost of constructing a LCHT with the benefits it can provide before making a decision regarding whether or not to use it as an alternative production system for organically grown strawberries.

Table 4. Best vs. poor yielding strawberry cultivar performance by production season and production system.

Performance	Season	System	Cultivar[z]
Best	2016–17	LCHT[y]	Strawberry Festival
	2017–18	OF[x]	Fla Radiance
	2019–20	LCHT	Fla Radiance
Poor	2016–17	OF	Fla Radiance
	2017–18	OF	Fla Beauty
	2019–20	OF	Fla Brilliance

[z]For cultivars evaluated by season and production mean values refer appropriately to Table 1, 2, and 3.
[y]LCHT = low cost high tunnel.
[x]OF = open field.

Table 5. Highest yielding strawberry cultivars[z] by production season and production system.

Season	System	Cultivar[z]
2016–17	OF	Winterstar™
	LCHT	Strawberry Festival
2017–18	OF	Fla Radiance
	LCHT	Fla Radiance
2019–20	OF	Fla Radiance
	LCHT	Fla Radiance

[z]For cultivars evaluated by season and production mean values refer appropriately to Table 1, 2, and 3.
[y]LCHT = low cost high tunnel.
[x]OF = open field.

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