Effects of Cultivar Selection and Placement of Shade Cloth on High Tunnels on Colored Bell Pepper Yield

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Introduction

Colored bell peppers provide an opportunity for vegetable growers to receive a price premium over unripened green bell peppers. Utilizing high tunnels to produce colored bell peppers increases fruit quality and ripening speed. Although there are benefits to high tunnel pepper production, high heat can lead to plant stress, blossom end rot, sunscald, and reduced marketable yields. The objective of this study was to identify colored bell pepper cultivars that perform well within high tunnels, plus test shade cloth treatments as a means to mitigate heat stress and improve fruit yield and quality.

Field research was conducted over two years (2017 and 2018) to compare the effect of three shade treatments (no shade cloth, 30% light-reducing shade cloth, and 50% light-reducing shade cloth) and seven colored bell pepper cultivars. This study was a randomized complete block design that included subplots within treatments.

Materials and Methods

Cultivars were selected to represent a range of common colors found in ripened bell peppers. Red cultivars were Archimedes and Red Knight (Seedway, LLC.). Yellow cultivars were Flavorburst (Seedway, LLC.), Summer Sweet (Rupp 2017, Harris Seeds 2018), and Sirius (Siegers Seed Co.). One orange cultivar, Delirio (Seedway, LLC), and one purple cultivar, Tequila (Seedway, LLC), also were included. Peppers were seeded in the ISU Department of Horticulture greenhouses March 26, 2017, and March 13, 2018, and managed based on standard commercial production practices.

Transplants were grown in the greenhouse for 5–6 weeks and then hardened off for 5–7 days. On May 11, 2017, and May 3, 2018, transplants were planted in six high tunnels with dimensions of 15 ft wide x 35 ft long covered with six-millimeter polyethylene film, which were arranged in two blocks. A block included three high tunnels each assigned to a single shade treatment. Transplants were planted in double rows (16 in. wide) with 12 inches in-row spacing. The two rows were offset by six inches creating a stagger. Each cultivar treatment consisted of six plants. Rows (subplots) were replicated three times within each high tunnel and were spaced three ft apart. Plants were supported using 5-ft wooden stakes and tomato twine. Drip tape irrigation system was utilized to water approximately 200 gallons/tunnel each week, with water held constant across shade treatments. Each high tunnel was mulched to a depth of six inches using switchgrass straw.

Two Hobo Onset data loggers were installed in each high tunnel to track irradiance and air temperature above the plant canopy. Two additional Hobo data loggers were buried six inches deep in each high tunnel to measure soil temperature. Data loggers also were placed outside of the high tunnels for comparison with high tunnel conditions. Data was analyzed from July 12 to September 23 across both years due to data loggers having to be moved in 2017 and ceasing to collect data after September 23, 2018.

The shade cloth used for this study was black-woven nylon sold as 30 and 50 percent light-reducing (Nolt's Produce Supplies, Charles City, IA). Shade cloth treatments were placed on respective high tunnels June 14, 2017, and June 19, 2018. The shade cloth remained on each high tunnel until the end of the season in both years. Harvest took place 15 times from July 5 to October 11, 2017, and 14 times from June 28 to October 4, 2018. Peppers were harvested each week when at least 80 percent of the fruit surface had turned from green to its respective color. The fruit was graded visually to determine marketability. Non-marketable fruit was sorted into categories based on sunscald, blossom end rot (BER), diseases, insect and rodent damage, size (diameter less than five centimeters), or fruit that was severely misshapen. Fruit count and weight was recorded for all categories of fruit for each harvest.

Post-harvest fruit quality was determined by collecting samples of fully-ripe, marketable fruit 112 days after transplanting for lab analysis each season. One whole fruit (calyx, seeds, and placenta removed) from each plot was blended in a food processor and sampled in a refractometer to measure soluble solids content (SSC, °Brix). Total titratable acidity also was measured using the same samples, but data is not shown.

Plant vigor was assessed at the end of the season using several parameters. All six plants in each plot were sampled for chlorophyll content using a SPAD meter October 11, 2017, and October 3, 2018. At the end of each season, all six plants/plot were measured for height from the soil to the highest shoot growing point October 11, 2017, and October 9, 2018. One plant from each plot was removed at the soil-line and dried completely to measure shoot biomass. A second plant in each plot was destructively sampled for leaf area measurement. All leaves from the plant were removed and counted. To determine leaf area, each individual leaf was analyzed on a LI-COR Area Meter. Both shoot biomass and leaf area samples were collected October 16-17, 2017, and October 9-10, 2018. Data was analyzed using PROC GLIMMIX of SAS Version 9.3.

Results and Discussion

The average level of irradiance inside of the high tunnels with 30 percent shade cloth was reduced by 39.5 percent, and the 50 percent shade cloth treatment caused a 57.5 percent reduction in irradiance compared with the high tunnels with no shade cloth ($P = 0.0036$). The use of shade cloth significantly reduced the average temperature within the high tunnels from 25.5°C (no shade cloth) to 24.2°C (30% shade) and 23.5°C (50% shade) ($P = 0.0114$). Maximum air temperature was reduced by 10.4 percent and 16.3 percent through the use of a 30 and 50 percent shade cloth, respectively, compared with maximum temperature in high tunnels without shade cloth ($P = 0.0094$).

In 2017 and 2018, the use of shade cloth significantly reduced the marketable number of fruit/plant from 7.7 (no shade cloth) to 5.2 (50% shade cloth) ($P = 0.0468$), but the marketable yield/plant (kg) was not reduced (Table 1). There was significant difference among cultivars for the number of marketable fruit/plant, which ranged from 4.8-11.6 fruit/plant ($P < .0001$), but there was no difference in marketable yield/plant (Table 1). The percent of marketable fruit ranged from 63.3-64.5 percent among shade treatments and 60.0-69.7 percent among cultivars, but neither effect was significant (Table 1). The total fruit yield(kg)/plant (marketable plus non-marketable) also was not significant for either shade or cultivar effects (Table 1).

The total fruit number/plant (marketable plus non-marketable) was reduced by the addition of shade cloth (P = 0.0023), and there were differences among cultivars for total fruit number/plant (P = 0.0002). A shade-by-cultivar interaction existed, and full results are shown in Table 2. The use of shade cloth did not decrease the average marketable fruit weight (weight divided by number, Table 2). Fruit weight did vary by cultivar, and Archimedes, Red Knight, and Sirius had the largest fruit by weight (Table 2). Again, a shade-by-cultivar interaction was found (Table 2).

The analysis of fruit quality found there was no effect of shade cloth use on SSC (°Brix) (Table 3). Archimedes, Flavorburst, and Summer Sweet had the highest SSC values with Tequila having the lowest, indicating a significant reduction in perceived sweetness (Table 3).

The use of shade cloth did not significantly affect plant height, shoot biomass, average leaf area, or leaf chlorophyll content (Table 4). These results were contrary to our expectation that pepper plants growing under reduced heat conditions would perform better, but the significant reduction of light levels may have negated the benefits of reducing heat stress. Cultivar variability was found for plant height (P = 0.0065), shoot biomass (P = 0.0002), and leaf chlorophyll content (P < .0001) as shown in Table 4. These results indicate cultivars such as Summer Sweet and Archimedes have increased vigor over other cultivars and this may be a benefit for withstanding heat-stress and/or low-light conditions, although this will need to be explored further.

Interestingly, the use of shade cloth did not reduce the incidence of sunscald or BER damage on fruit (Table 5). However, differences in fruit damage were observed among bell pepper cultivars as affected by sunscald and BER (Table 5). Tequila fruit had the lowest incidence of sunscald and BER, which may be due to its smaller fruit size, making it more easily shaded by the plant leaves for protection from sun-induced damage.

The results of this work showed the use of a 30 or 50 percent light-reducing black nylon shade cloth may not increase plant vigor, improve fruit quality, or significantly reduce the incidence of sunscald or BER for colored bell pepper production. Growers should carefully consider the use of shade cloth due to potential negative impacts on marketable and total yield for colored bell pepper production. Prior research has shown low light levels can lead to increases in flower and fruit abortion. High heat also can cause abortion of flowers and fruit, so a balance between heat mitigation and light reduction must be reached. Future work may include exploration of lower levels of light reduction (10–20% light-reducing shade cloths). Although cost is prohibitive for many growers, the addition of roof-vents to high tunnels may provide a greater effect in heat mitigation and would not compromise light levels within the tunnel.

Apart from the use of shade cloth, this work found some promising colored bell pepper cultivars for high tunnel production systems. Tequila (purple) and Flavorburst (yellow) had the highest number of marketable fruit/plant. However, the small fruit size and low SSC of Tequila may not appeal to all consumers. Archimedes (red), Red Knight, and Sirius (yellow) all had large fruit size that may be desirable for direct-to-consumer markets. While Archimedes, Flavorburst, and Summer Sweet (yellow) had the highest SSC, the difference may not be discernable to most consumers. The use of any colored bell pepper cultivar should be considered carefully based on the high tunnel production system and the market that will be utilized.

Overall, the production of colored bell peppers in Iowa high tunnels looks promising, although more research is needed to improve the production system and manage the high tunnel climate for optimum yields.

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Table 1. Marketable fruit/plant, percent marketable fruit, and total fruit/plant (yield) from peppers grown under no-shade, 30%, and 50% shade treatments. *

	Marketable fruit/plant		**Percent marketable**	**Total fruit/plant**
	No. of fruit	**Yield (kg)**	**no. of fruit (%)**	**Yield (kg)**
Shade				
No shade cloth	7.7 a**	1.4	63.3	2.7
30% shade	5.9 ab	1.1	64.4	2.0
50% shade	5.2 b	1.0	64.5	1.8
P value	0.0468	0.1066	0.9400	0.0584
Cultivar				
Archimedes	5.1 c	1.2	63.2	2.2
Delirio	6.0 cb	1.1	64.8	2.1
Flavorburst	6.4 b	1.1	67.9	2.1
Red Knight	5.0 c	1.1	69.7	2.1
Sirius	4.8 c	1.1	60.1	2.1
Summer Sweet	4.8 c	1.0	60.0	2.1
Tequila	11.6 a	1.3	62.2	2.3
P value	<.0001	0.7146	0.6308	0.7302

P values indicate significance of the main effect of treatment based on F-test.
There was no significant interaction between year, shade, or cultivar.
*Plants were harvested 15 times from July 5–October 11, 2017, and 14 times from June 28–October 4, 2018.
**Means within a column and category (shade and cultivar) followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher's protected least significant difference test.

Table 2. Total pepper fruit/plant and average marketable fruit weight grown under no-shade, 30%, and 50% shade treatments.*

	Total fruit/plant**	
	No. of fruit	Avg. marketable fruit weight (g)**
No shade cloth		
Archimedes	10.4 b	231.8 a
Delirio	11.6 b	178.3 c
Flavorburst	11.0 b	181.9 c
Red Knight	9.5 b	221.3 ab
Sirius	9.6 b	217.7 ab
Summer Sweet	10.3 b	207.0 b
Tequila	23.8 a	105.5 d
30% shade		
Archimedes	7.0 bc	213.4 a
Delirio	8.5 b	186.3 b
Flavorburst	9.2 b	166.8 b
Red Knight	6.1 c	231.5 a
Sirius	7.3 bc	212.8 a
Summer Sweet	7.7 bc	221.0 a
Tequila	18.4 a	108.6 c
50% shade		
Archimedes	6.2 bc	243.1 a
Delirio	7.3 bc	189.0 b
Flavorburst	7.9 b	178.4 b
Red Knight	5.7 c	237.7 a
Sirius	7.0 bc	229.5 a
Summer Sweet	5.8 c	198.0 b
Tequila	15.3 a	115.3 c
P value		
Shade (S)	0.0023	0.4681
Cultivar (C)	0.0002	0.0008
S x C	0.0054	0.0367

P values indicate significance of the main effects based on F-test.
There was no significant interaction with year.
*Plants were harvested 15 times from July 5-October 11, 2017, and 14 times from June 28-October 4, 2018. Due to a significant interaction between shade and cultivar, the data is presented accordingly.
**Means within each shade treatment column followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher's protected least significant difference test.

Table 3. Pepper soluble solids content (SSC) peppers grown under no-shade, 30%, and 50% shade treatments.*

Treatments	**SSC (°Brix)**
Shade	
No shade cloth	6.9
30% shade	6.9
50% shade	7.1
P value	0.9760
Cultivar	
Archimedes	8.1 ab**
Delirio	7.2 bc
Flavorburst	7.4 abc
Red Knight	6.9 c
Sirius	6.8 c
Summer Sweet	8.5 ab
Tequila	4.3 d
P value	<.0001

P values indicate significance of the main effect of treatment based on F-test.

There was no significant interaction between year, shade, or cultivar.

*Fully ripe fruit were harvested 112 days after transplanting in 2017 and 2018.

**Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher's protected least significant difference test.

Table 4. Final height, shoot biomass, average leaf area, and leaf chlorophyll content (SPAD) of peppers grown under no-shade, 30%, and 50% shade treatments.*

	Plant height (cm)*	Shoot biomass (g)*	Avg. leaf area (cm^2)†	SPAD
Shade				
No shade cloth	94.9	95.2	33.0	54.0
30% shade	107.4	89.9	35.7	55.7
50% shade	113.8	108.8	44.0	56.7
P value	0.2043	0.6897	0.0800	0.4353
Cultivar				
Archimedes	107.0 ab**	117.4 a	43.1	57.2 ab
Delirio	104.7 b	86.9 bc	35.6	55.2 bc
Flavorburst	105.4 bc	83.0 c	36.1	54.2 c
Red Knight	96.5 c	86.8 bc	35.5	58.9 ab
Sirius	107.1 ab	108.8 a	38.3	53.7 c
Summer Sweet	114.9 a	104.1 a	38.3	59.9 a
Tequila	101.8 bc	98.7 ab	36.1	49.0 d
P value	0.0065	0.0002	0.5229	<.0001

P values indicate significance of the main effect of treatment based on F-test.
There was no significant interaction between year, shade, or cultivar.
*Height data collected October 11, 2017, and October 9, 2018. SPAD data collected October 11, 2017, and October 3, 2018. Shoot biomass and leaf area collected October 16, 2017, and October 9, 2018.
†Avg. leaf area = total leaf area/number of leaves/plant.
**Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher's protected least significant difference test.

Table 5. Incidence (%) of sunscald and blossom end rot (BER) in fruit collected from peppers grown under no-shade, 30%, and 50% shade treatments.*

Treatment	Sunscald (%)	BER (%)
Shade		
No shade cloth	2.9	7.9
30% shade	2.2	4.3
50% shade	1.2	4.9
P value	0.4064	0.7432
Cultivar		
Archimedes	2.6 a**	4.7 ab
Delirio	2.3 a	6.9 ab
Flavorburst	2.4 a	3.4 b
Red Knight	1.8 a	5.2 ab
Sirius	2.6 a	11.1 a
Summer Sweet	2.3 a	7.0 ab
Tequila	0.6 b	1.5 c
P value	0.0106	0.0150

P values indicate significance of the main effect of treatment based on F-test.
There was no significant interaction between year, shade, or cultivar.
*Harvest occurred 15 times from July 5–October 11, 2017, and 14 times from June 28–October 4, 2018.
**Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ based on Fisher's protected least significant difference test.