On-farm Evaluation of Strawberry Cultivars in Coastal Virginia

Roy D. Flanagan III[1], Jayesh B. Samtani[2],
Mikel Ann Manchester[2], Stephanie Romelczyk[3],
Charles S. Johnson[4], Watson Lawrence[5], and Jeremy Pattison[6]

Additional index words. **annual hill plasticulture production, day-neutral, *Fragaria ×ananassa*, short-day**

Summary. **Strawberries (*Fragaria ×ananassa*) are one of the major high-value crops in North America. There is increasing interest in commercial strawberry production for local markets in Virginia and surrounding states, but information on the performance of newer cultivars is extremely limited. We tested 10 commercially available June-bearing cultivars [Benicia, Camarosa, Camino Real, Chandler, Strawberry Festival, Flavorfest, FL Radiance, Treasure, Sweet Charlie, and Winterstar™ (FL 05-107)] and two day-neutral cultivars (Albion and San Andreas) for their spring and summer fruiting capacity in Virginia production systems in a randomized, replicated study, at three on-farm locations. Data were collected on vegetative growth, yield performance, fruit quality, sweetness, and fruit diameter. Cultivars with the highest total yields averaged across all three locations were Benicia, Camino Real, Chandler, and Camarosa. 'Camino Real' had the highest marketable yield at all three locations, not significantly different from 'Chandler', and 'Benicia' and 'Camarosa' had the highest marketable yield at two of the three locations. 'Flavorfest' and 'Sweet Charlie' had the highest total soluble solids concentration for the harvest season. Overall, for all locations, 'Benicia' and 'Camino Real' had the largest fruit diameter, and 'Strawberry Festival' had the smallest fruit diameter.**

The south-Atlantic region, which includes the Commonwealth of Virginia, is the third-largest producing region for fresh market strawberries following California and Florida (Samtani et al., 2019). The most recent agriculture census for the Commonwealth of Virginia indicated 296 farms growing strawberries on 391 acres [U.S. Department of Agriculture (USDA), 2019]. Strawberry production in the state is predominantly targeted toward direct markets (Christman and Samtani, 2019; Samtani et al., 2019). Most strawberry acreage in Virginia is grown using the annual hill plasticulture (AHP) production system, where plug plants are transplanted in the fall for harvest in the spring (Christman and Samtani, 2019). Similar to surrounding states (Delaware, Maryland, the Carolinas, and West Virginia) the AHP strawberry growers in Virginia have mainly grown three cultivars: Chandler and Camarosa, developed by the University of California, Davis, and Sweet Charlie, developed by the University of Florida (Hokanson and Finn, 2000; Poling et al., 2005). These three cultivars were bred for the commercial pre-pick and shipping markets for their intended geographic locations, but have been adapted for you-pick/direct to consumer markets in the mid-Atlantic and the south-Atlantic region of the United States.

The phenotypic response of strawberry cultivars changes depending on the climatic and geographic area in which they are grown (Antunes et al., 2010; Kaps et al., 2003). Most strawberry cultivars in the United States are released from California and Florida public and private breeding efforts. Strawberry crop sustainability and profitability in other regions of the country can be improved by evaluating and adopting cultivars for specific climatic conditions of each region. Grower adoption of strawberry cultivar is driven by factors such as processing and marketing practices, resistance to insect and disease pests, and higher-quality fruit (Shaw and Larson, 2008).

Studies on evaluation of strawberry cultivars or cultural systems has been limited in the midsouthern United States (Ballington et al., 2008; Gu et al., 2017). The objective of this research was to evaluate yield and fruit quality characteristics of newer strawberry cultivars grown in the AHP system in coastal Virginia climatic conditions (USDA Plant Hardiness zones 7 and 8).

Materials and methods

On-farm studies were initiated in Fall 2013, to evaluate commercially available strawberry cultivars Albion, Benicia, Camarosa, Camino Real, Chandler, Strawberry Festival, Flavorfest, FL Radiance, San Andreas, Sweet Charlie, Treasure, and Winterstar™ (FL 05-107). Strawberry plug plant material was supplied by the North Carolina State University breeding program, except for 'Flavorfest', which was provided by Kube-Pak (Allentown, NJ), and 'Camarosa' and 'Chandler', from Aarons Creek Nursery (Buffalo Junction, VA). Studies were established at three locations in the coastal plain of Virginia: in the City of Chesapeake (lat. 36.836045°N, long. 76.398461°W; USDA Plant Hardiness Zone 7b), in the City of Virginia Beach (lat. 36.714832°N, long. 76.016372°W; USDA Plant Hardiness Zone 8a), and Westmoreland County (lat. 38.130043°N, long. 77.047534°W; USDA Plant Hardiness Zone 7a). All

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
0.0094	gal/acre	$m^3 \cdot ha^{-1}$	106.9066
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
0.0254	mil(s)	mm	39.3701
28.3495	oz	g	0.0353
33.9057	oz/yard^2	$g \cdot m^{-2}$	0.0295
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

three locations provided preplant soil amendments, drip irrigation, frost protection, spring fertility, and pest control on an as-needed basis. Soil samples from each location were submitted to the Virginia Tech Soils Testing Laboratory, Blacksburg, VA, before the establishment of study. Lime and fertilizer dosage were applied as per recommendations of the soil testing laboratory and based on standard commercial practices for the region (Poling et al., 2005). The study at all locations was done in a randomized complete block design with three replicates. Additional background information about each location can be found in Tables 1 and 2.

Plant stand counts and visual plant health ratings were collected monthly for each replicate beginning on 6 Nov. 2013 (Chesapeake), 30 Oct. 2013 (Virginia Beach), and 28 Oct. 2013 (Westmoreland County). The plant health visual ratings used a scale of 0 = all plants dead in a replicate to 10 = all plants in a replicate looking healthy and vigorous. We were unable to completely characterize our health ratings, as these are influenced by both abiotic and biotic factors affecting crop production. Also, changes in plant growth and development over the period of the growing season make following a standard rating chart difficult. In our study, attributes including smaller crop leaf canopy, foliar diseases, yellowing and browning of foliage, resulted in a lower plant health rating. Plant leaf canopy diameter measurements were taken for all plants in the spring season on 20 Mar. 2014, in the cities of Chesapeake and Virginia Beach and on 11 Mar. 2014 in Westmoreland County.

Harvest for the season began as soon as ripe fruit was present in the spring and ended when all short-day cultivars had no marketable fruit left on the plant. Fruit by replicate on all crop plants were harvested two to three times per week during the harvest period. In Chesapeake, harvest began on 1 May 2014 and ended on 6 June 2014; in Virginia Beach, the harvest period was from 2 May 2014 through 12 June 2014; and in Westmoreland County, harvest began on 8 May 2014 and ended on 2 June 2014. Total yield, marketable yield, nonmarketable yield, average fruit diameter, and total soluble solids (TSS) concentration were calculated over the whole season. At each harvest, fruit were separated into marketable and nonmarketable categories in the field. Marketable fruit comprised fruit that was 90% to 100% red in color on the external surface with calyx attached, and free of mold, diseases, insect, bird, or animal bites. 'Camino Real' was picked at a deeper red stage due to its dark external fruit color (Shaw and Larson, 2002). Unmarketable fruit represented misshapen, diseased, or deformed fruit and small fruit less than 10 g in weight. Small fruit were placed individually on the weighing scale to determine their category. Cumulative weights of marketable and nonmarketable fruit per replicate were calculated for the season and divided by the number of plants per replicate, and then expressed as yield per plant. Fruit diameter was measured once each harvest week, on five marketable berries per replicate, using a digital Vernier caliper (Neiko 01407A Electronic Digital Caliper; Neiko Tools, Wenzhou, China). Readings (millimeters) were recorded at the widest point on the berry, which was usually just below the proximal end. After measuring fruit diameter, berry calyces were removed, and the five fruit from each replicate were placed in a labeled, polyethylene freezer bags. These freezer bags were transported from the field site in coolers with freezer packs and placed in a laboratory freezer at –14.5 °C. After the harvest season, freezer bags, each containing five berries, were removed from the freezer, thawed, crushed, and sieved to separate the juice from the pulp. TSS concentrations (%) were determined with a refractometer (MA 871; Milwaukee Instruments Inc., Rocky Mount, NC) at 21 °C.

Data analysis. Data were checked for normality of residuals before running the analysis of variance (ANOVA). A two-way analysis of location by cultivar was performed using JMP Pro software (version 13; SAS Institute, Cary, NC) for the dependent factors including plant canopy diameter, crop yields, fruit diameter, and TSS. Canopy readings were averaged across subsamples before statistical analysis (Purdue University, 2017). For each replicate, fruit diameter, and TSS readings were averaged for the whole harvest season and ANOVA was run on the season average. Data were analyzed separately by location when the location by cultivar interaction was significant for a dependent factor at $\alpha = 0.05$. If the interaction was not significant, data were pooled to evaluate the significant main effects. Apparent differences among means were evaluated using the Fisher's protected least significant difference test.

Results and discussion

Plant health ratings and crop stand count. Qualitative health ratings were performed for all cultivars 1 month after transplanting. At this time, at all farms, average health ratings for the season were in the 7.0 to 9.2 range for all cultivars, except Flavorfest, which averaged a health rating of 6.5 in Virginia Beach and Chesapeake, and 6.3 at Westmoreland County. At transplanting, 'Flavorfest' plug plants exhibited symptoms of angular leaf spot (*Xanthomonas fragariae*). These symptoms subsided by late November

Received for publication 24 Mar. 2020. Accepted for publication 31 Aug. 2020.

Published online 6 October 2020.

[1]Virginia Cooperative Extension, 2449 Princess Anne Road, Virginia Beach, VA 23456

[2]Hampton Roads Agricultural Research and Extension Center, School of Plant and Environmental Sciences, Virginia Polytechnic Institute and State University, 1444 Diamond Springs Road, Virginia Beach, VA 23455

[3]Virginia Cooperative Extension, 18849 Kings Highway, Montross, VA 22520

[4]Southern Piedmont Agricultural Research and Extension Center, School of Plant and Environmental Sciences, Virginia Polytechnic Institute and State University, 2375 Darvills Road, Blackstone, VA 23824

[5]Virginia Cooperative Extension, 310 Shea Drive, Chesapeake, VA 23322

[6]Driscoll's, Inc., 151 Silliman Road, Watsonville, CA 95076

This activity was funded, in part, with an integrated, internal competitive grant from Virginia Agricultural Experiment Station, Virginia Cooperative Extension, the College of Agriculture and Life Sciences and Open-Access Subvention Fund at Virginia Polytechnic Institute and State University. We thank Lilley Farms, Westmoreland Berry Farm, and Flanagan Farm for hosting the study. We extend our gratitude to Kelly Jacobson, Sydney Covey, Samridhi Vashisth, Sanghamitra Das, and Robbie Longest for assistance with data collection. Thanks to Toktam Taghavi and Edgar Vinson for reviewing the manuscript before its submission.

J.B.S. is the corresponding author. E-mail: jsamtani@vt.edu.

https://doi.org/10.21273/HORTTECH04616-20

Table 1. Farm-specific preplant fumigation or herbicide treatment details for the strawberry cultivar trials in the 2013–14 growing season in the cities of Chesapeake and Virginia Beach and Westmoreland County, VA.

Location	Preplant treatment	Treatment date	Treatment rate (lb/acre)[z]	Treatment equipment	Predominant soil type	No./ cultivar/ replicate[y,x]
City of Chesapeake	1,3-dichloropropene (63.4%) + chloropicrin (34.7%) (Telone C-35; TriEst Ag Group, Greenville, NC)	24 Aug. 2013	135	Three knives system on a Reddick mulch layer (TriEst Ag Group, Greenville, NC)	Bojac fine sandy loam (coarse-loamy, very deep, well drained, parent material: loamy and sandy fluvial and marine sediments), in 0% to 10% slope	20 plants[w]
City of Virginia Beach	1,3-dichloropropene (39%) + chloropicrin (59.6%) (Pic-Clor60; TriEst Ag Group)	1 Sept. 2013	120	Two knives system on a Reddick mulch layer (TriEst Ag Group)	State loam (fine-loamy, very deep, well drained, parent material: Alluvium), normally found in 0% to 10% slope	30 plants[v]
Westmoreland County	Napropamide (Devrinol® 50-DF; United Phosphorus, Inc., King of Prussia, PA)	24 Sept. 2013	8	Bed top application with a Rain-Flo mulch layer (Rain-Flo Irrigation, East Earl, PA)	Pamunkey fine sandy loam (fine-loamy, deep, well drained, parent material: weathered igneous and metamorphic rocks), normally found in 0% to 15% slope	20 plants[u]

[z]1 lb/acre = 1.1209 kg·ha^{-1}.
[y]Experimental design was randomized complete block design with three replications.
[x]All locations used 1.25 mil (1 mil = 0.0254 mm) black embossed virtually impermeable film and 10 mil, 0.5 gal/h (1.89 L·h^{-1}) with 12-inch (1 inch = 2.54 cm) emitter spaced dripline (Chapin; Jain Irrigation, Inc., Watertown, NY) placed 0.5 inch below soil line at top of bed. All locations had bed dimensions of 30 inches wide by 8 inches high.
[w]Exception being 'Flavorfest' established at 15 plants per replicate.
[v]Exception being 'Flavorfest' established at 20 plants per replicate.
[u]Exception being 'Benicia' established at 16 plants per replicate and 'Flavorfest' at 15 plants per replicate because of fewer healthy plug plants.

Table 2. Strawberry planting date, plant spacing, and frost protection strategies for three on-farm locations in coastal Virginia during the 2013–14 growing season.

Location	Planting date	Plant spacing (inches)[z,y]	Row spacing (ft)[x,w]	Frost protection strategy
City of Chesapeake	3 Oct. 2013	12 × 12	5	Overhead irrigation, 3498 gal/acre (32.7 m^3·ha^{-1}) per hour
City of Virginia Beach	29 Sept. 2013	16 × 14	6	1.2 oz/yard^2 (40.69 g·m^{-2}) rowcover (Du Pont 5131, Typar T-518; DuPont, Wilmington, DE)
Westmoreland County	27 Sept. 2013	14 × 12	5	1.2 oz/yard^2 rowcover (Atmore Industries, Atmore, AL)

[z]First number is distance between plants, and the second number is distance between rows on the bed.
[y]1 inch = 2.54 cm.
[x]1 ft = 0.3048 m.
[w]Row orientation at all locations was east-west.

and did not negatively influence plant health rating after that date. By March, Albion was the only cultivar that had an average health rating between 6.0 and 7.0, which was attributed to smaller plants relative to other cultivars. Gu et al. (2017) also reported a smaller canopy diameter for 'Albion' compared with other cultivars. The initial plant stand (listed in Table 1) and the final plant stand (data not shown) for the season remained unchanged.

Crop canopy. Both location and cultivar affected plant canopy diameter. In general, plants at the Chesapeake location had the greatest canopy diameter (25.5 cm), significantly more than those in Westmoreland County (22.4 cm) and Virginia Beach (15.0 cm). Plants at the Virginia Beach location had the smallest canopy diameter. The cause of location effect is not very clear considering the earlier planting date and wider plant spacing at Virginia Beach than at Chesapeake (Table 2); but, other environmental and cultural practices including irrigation, fertigation, and rowcover management may have influenced crop canopy.

Similar to observations by Gu et al. (2017), crop canopy diameter was lowest for 'Albion' in our study (Table 3). Canopy diameter for 'Flavorfest', 'Strawberry Festival', and 'Camino Real' were larger than for 'Albion', but similar to each other. Both Camino Real and Albion were described as relatively compact cultivars at their times of release (Shaw and Larson, 2002, 2006). Canopy size for other cultivars in our study was not

Table 3. Strawberry cultivar effect on spring season crop canopy diameter and total yield, marketable to nonmarketable yield ratio, length of harvest season averaged across locations in Virginia during the 2014 harvest season.

Cultivar[z]	Cultivar origin	Canopy diam (cm)[y]	Total yield (g/plant)[x]	Marketable/ nonmarketable fruit (ratio)	Harvest season (d)
Albion	University of California, Davis, CA[y]	17.2 e[w]	347.5 e[w]	4.0:1	35.3
Benicia	University of California, Davis, CA	22.6 ab	656.7 a	2.0:1	33.7
Camarosa	University of California, Davis, CA	21.6 abc	571.9 abc	3.1:1	34.0
Camino Real	University of California, Davis, CA	20.4 cd	641.1 ab	4.7:1	35.3
Chandler	University of California, Davis, CA	21.5 abc	626.2 ab	2.8:1	35.3
Flavorfest	United States Department of Agriculture, Agricultural Research Center, Beltsville, MD	19.2 d	480.6 cd	2.2:1	31.0
Florida Radiance	University of Florida, Gainesville, FL	21.8 abc	355.7 e	1.5:1	35.3
San Andreas	University of California, Davis, CA	21.0 bc	556.6 bc	1.4:1	34.0
Strawberry Festival	University of Florida, Gainesville, FL	20.6 cd	388.4 de	4.1:1	35.3
Sweet Charlie	University of Florida, Gainesville, FL	22.7 a	354.5 e	4.3:1	35.3
Treasure	P. Chang, Naples, FL	21.6 abc	489.2 c	2.1:1	35.3
Winterstar™ (FL 05-107)	University of Florida, Gainesville, FL	21.3 abc	386.8 de	1.6:1	34.0

[z]Cultivars evaluated were short-day types except for Albion and San Andreas, which were day-neutral types. The day-neutral cultivars were treated as short-day cultivars.
[y]1 cm = 0.3937 inch.
[x]1 g = 0.0353 oz.
[w]Means with the same letter within a column are not significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

Table 4. Effect of location and cultivar on marketable yield of 12 strawberry cultivars in annual hill plasticulture production system in the 2013–14 growing season in the cities of Chesapeake and Virginia Beach and Westmoreland County, VA.

	City of Chesapeake[y]	City of Virginia Beach	Westmoreland County
Cultivar[z]	Marketable yield (g/plant)[x]		
Albion	218.9 de[w]	467.4 de	145.8 e
Benicia	313.6 ab	572.1 cd	420.6 a
Camarosa	318.6 ab	648.0 bc	333.6 abc
Camino Real	363.1 a	839.2 a	383.6 ab
Chandler	339.4 a	753.5 ab	284.2 bcd
Flavorfest	251.5 bcd	513.0 de	219.9 de
Florida Radiance	156.7 e	257.6 g	229.8 cde
San Andreas	222.0 de	467.4 de	274.0 cd
Strawberry Festival	218.6 de	479.7 de	237.4 cde
Sweet Charlie	301.5 abc	417.9 ef	141.4 e
Treasure	239.3 cd	470.6 de	284.1 bcd
Winterstar™ (FL 05-107)	185.9 de	341.1 fg	180.7 de

[z]Cultivars evaluated were short-day types except for Albion and San Andreas, which were day-neutral types. The day-neutral cultivars were treated as short-day cultivars in our study.
[y]The location by cultivar interaction was significant ($P = 0.001$). Data are analyzed separately for each location.
[x]1 g = 0.0353 oz.
[w]Means with the same letter within a column are not significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

different. Torres-Quezada et al. (2015) found no cultivar effects on canopy diameter at 6 and 18 weeks after transplanting of bare-root transplants for Florida cultivars Florida Radiance, Strawberry Festival, and Winterstar™ (FL 05-107). In our study, for the whole season yield, there was a negative correlation with yield and spring canopy diameter readings for all the cultivars (correlation data not shown). For 'Albion', 'Camarosa', and 'Strawberry Festival', a lower canopy size did not necessarily result in a lower yield in a California study (Samtani et al., 2012). The size of crop canopy during the spring season may not be a very good predictor of yield potential in the strawberry crop.

Fruit yield and quality parameters. Harvest season lasted 7 weeks in Virginia Beach (2 May through 12 June), 6 weeks in Chesapeake (1 May through 6 June), and 5 weeks in Westmoreland County (5 May through 2 June). Crop yield for the season was influenced by cultivars. Cultivar yields from Benicia, Camino Real, and Chandler were higher than those for Treasure, Flavorfest, Strawberry Festival, Winterstar™ (FL 05-107), Florida Radiance, Sweet Charlie, and Albion (Table 3). Total yield for 'Albion', 'Florida Radiance', and 'Sweet Charlie' were lower than for all other cultivars except 'Strawberry Festival' and 'Winterstar™' (Table 3). 'Camino Real', 'Albion', 'Strawberry Festival', and 'Sweet Charlie' had the highest ratio of marketable to nonmarketable yield. Shaw and Larson (2002, 2006) described 'Camino

Table 5. Marketable harvest yield by week in 2014 of select strawberry cultivars in annual hill plasticulture production system at three on-farm locations in coastal Virginia.

Cultivar	Marketable yield (g/plant)[z]						
	Week 1[y]	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
				City of Chesapeake			
Albion	1.4	40.2	97.5	48.6	28.4	2.8	–[x]
Benicia	4.0	42.6	155.6	83.7	26.4	1.3	–
Camarosa	0.2	21.8	133.5	123.5	37.5	2.1	–
Camino Real	4.4	51.5	169.2	108.1	24.3	5.6	–
Chandler	9.4	28.7	129.0	125.5	43.9	2.9	–
Flavorfest	0.0	29.3	98.4	98.7	23.2	1.9	–
Florida Radiance	0.9	35.1	71.0	38.7	10.4	0.6	–
San Andreas	1.0	27.9	101.7	50.0	37.3	4.1	–
Strawberry Festival	2.3	35.9	96.6	72.4	11.1	0.3	–
Sweet Charlie	12.1	100.0	147.1	34.6	3.7	4.0	–
Treasure	4.8	20.0	91.3	92.8	27.3	3.1	–
Winterstar™ (FL 05-107)	3.9	30.3	76.0	62.3	11.9	1.5	–
				City of Virginia Beach			
Albion	0.3	8.7	124.6	160.4	95.2	38.2	40.0
Benicia	2.1	26.8	184.0	283.3	65.9	2.6	7.4
Camarosa	0.2	6.5	144.5	330.0	148.8	12.0	6.0
Camino Real	0.2	31.2	305.5	354.8	102.7	16.7	28.1
Chandler	0.3	7.3	210.0	360.5	136.3	20.5	18.6
Flavorfest	0.0	35.0	95.5	233.9	131.8	12.9	3.9
Florida Radiance	0.3	6.6	74.0	125.9	43.7	1.2	5.9
San Andreas	0.0	12.8	139.7	210.6	96.4	3.3	4.6
Strawberry Festival	4.8	40.3	160.5	192.7	73.5	5.5	2.4
Sweet Charlie	8.3	79.1	202.4	75.4	8.8	21.6	22.3
Treasure	3.2	17.6	126.8	224.0	79.8	13.7	5.5
Winterstar™ (FL 05-107)	0.0	17.9	129.7	134.9	48.7	4.3	5.6
				Westmoreland County			
Albion	–[w]	16.8	62.1	37.7	21.6	7.6	–
Benicia	–	96.8	189.0	119.6	15.2	0.0	–
Camarosa	–	69.1	122.7	98.3	37.6	5.9	–
Camino Real	–	57.5	118.9	125.4	68.4	13.4	–
Chandler	–	43.5	82.0	109.0	41.1	8.6	–
Flavorfest	–	2.5	87.8	86.7	37.0	5.9	–
Florida Radiance	–	39.0	100.4	63.2	23.0	4.2	–
San Andreas	–	44.9	123.8	65.6	31.5	8.2	–
Strawberry Festival	–	103.5	74.0	46.2	12.3	1.4	–
Sweet Charlie	–	51.9	58.4	26.6	2.4	2.1	–
Treasure	–	62.7	127.7	71.4	20.9	1.4	–
Winterstar™ (FL 05-107)	–	48.6	83.5	36.7	10.6	1.3	–

[z]1 g = 0.0353 oz.
[y]Week 1 = 1 to 3 May; week 2 = 4 to 10 May; week 3 = 11 to 17 May; week 4 = 18 to 24 May; week 5 = 25 to 31 May; week 6 = 1 to 6 June; week 7 = 7 to 13 June.
[x]There was no yield in week 7 of the harvest season in City of Chesapeake.
[w]There was no yield in weeks 1 and 7 of the harvest season in Westmoreland County.

Real' and 'Albion' as having lower cull rates. In our trial, fruit rot caused by botrytis (*Botrytis cinerea)*, anthracnose (*Colletotrichum acutatum*), and sunscald were the primary biotic and abiotic factors limiting marketable yield at all locations. Anthracnose fruit rot was observed during the harvest of weeks 3 and 4 at all locations. The heaviest infections of anthracnose fruit rot were observed on 'San Andreas' and 'Benicia' in the City of Chesapeake (data not shown). Throughout the harvest period, at all locations, some sunscald was found on all cultivars, with the heaviest damage on 'San Andreas' fruit at all three locations (J.B. Samtani, personal observations). These observations are reflected in the marketable to nonmarketable yield ratio presented in Table 3.

There was a significant location by cultivar interaction for marketable yield for the season (Table 4). Data for each location were analyzed separately. In the City of Chesapeake, the highest marketable yield was observed in 'Camino Real' and 'Chandler'. Other cultivars including Benicia, Camarosa, and Sweet Charlie had statistically similar yields to Camino Real and Chandler. In the City of Virginia Beach, the highest yielding cultivars were Camino Real and Chandler. 'Camarosa' yield was similar to 'Chandler', but lower than 'Camino Real'. 'Florida Radiance' was the lowest yielding cultivar in the Virginia Beach location and was similar to 'Winterstar™' (FL 05-107) yield. In Westmoreland County, Benicia

Table 6. Interaction effect of location and cultivar on mean fruit diameter (at the widest point of the berry) of select strawberry cultivars grown at three on-farm locations in coastal Virginia in 2014 harvest season.

Cultivar[z,y]	City of Chesapeake	City of Virginia Beach	Westmoreland County
	Fruit diam (mm[x])		
Albion	33.3 abc[w]	38.3 a	33.6 c–e
Benicia	36.2 a	36.5 b	39.2 a
Camarosa	32.0 cd	33.4 de	33.8 b–e
Camino Real	35.3 ab	37.2 ab	36.1 b
Chandler	31.4 cd	34.0 cd	34.1 b–d
Flavorfest	31.2 cd	35.2 c	35.2 bc
Florida Radiance	33.6 abc	34.3 cd	33.1 c–f
San Andreas	33.4 abc	34.9 cd	35.3 bc
Strawberry Festival	29.6 d	31.9 f	29.9 g
Sweet Charlie	31.9 cd	34.1 cd	31.2 fg
Treasure	32.4 bcd	33.3 de	31.7 efg
Winterstar™ (FL 05-107)	29.7 d	34.9 cd	32.2 d–g

[z]Cultivars evaluated were short-day types except for Albion and San Andreas, which were day-neutral types.
[y]The location by cultivar interaction was significant ($P = 0.001$). Data are analyzed separately for each location.
[x]1 mm = 0.0394 inch.
[w]Means with the same letter within a column are not significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

Table 7. Range of total soluble solids concentration [TSS (%)] of 12 strawberry cultivars in annual hill plasticulture production system in the 2014 harvest season in the cities of Chesapeake and Virginia Beach and Westmoreland County, VA.

Cultivar[z]	City of Chesapeake	City of Virginia Beach	Westmoreland County
	TSS concn (%) range		
Albion	8.9–6.5	8.6–6.7	8.9–7.2
Benicia	8.4–5.4	9.9–4.4	6.9–4.9
Camarosa	8.0–5.6	8.7–5.6	9.6–6.7
Camino Real	7.8–5.5	5.3–4.8	7.7–5.7
Chandler	9.6–5.2	9.9–6.3	8.4–7.2
Flavorfest	8.5–6.5	7.6–6.8	10.4–7.2
Florida Radiance	7.1–5.3	8.0–4.5	7.5–5.4
San Andreas	7.4–5.3	6.7–5.4	7.5–6.0
Strawberry Festival	8.5–5.4	8.9–6.5	9.2–6.9
Sweet Charlie	10.5–6.5	10.3–6.9	8.6–7.3
Treasure	9.1–5.4	8.5–5.6	7.9–6.0
Winterstar™ (FL 05-107)	7.6–5.4	7.9–5.7	8.2–5.9

[z]Cultivars evaluated were short-day types except for Albion and San Andreas, which were day-neutral types.

was the highest yielding cultivar, but not different from Camarosa and Camino Real. Yield data for the highest yielding cultivars are presented by harvest week in Table 5. May was the peak month of harvest. The yield of 'Florida Radiance' in our open field was not as high as yield observed by Gu et al. (2017) under the high-tunnel environment. 'Florida Radiance' can produce more flowers under long-day conditions than traditional short-day cultivars, thus performing better in the protected culture environment (Whitaker et al., 2013). 'Sweet Charlie' yielded moderately well at Chesapeake location compared with Virginia Beach and Westmoreland County. Significant cultivar by environment interaction can result from differences in planting date, plant density, and environment (Lopez-Medina et al., 2001). Factors such as row and plant spacing, irrigation and fertigation, bed dimensions, and preplant pest treatments influence crop yield. In our study, the plants were spaced wider in Virginia Beach and that seemed to have a positive response on marketable yield per plant. In three different environments across California, in 47 strawberry cultivars, significant genetic differences to powdery mildew (*Sphaerotheca macularis*) were demonstrated (Nelson et al., 1996). Environmental factors such as soil pH, available potassium, and phosphorus fertility accounted for a large amount of the cultivar by environment interaction (Ortiz et al., 2007).

There was also a significant location by cultivar interaction effect on berry fruit diameter. Data for each location were analyzed separately. There was very little separation among cultivars at the Chesapeake location, but Albion had the largest fruit diameter at Virginia Beach, although similar to 'Camino Real' (Table 6). 'Benicia' had the largest fruit diameter at the Westmoreland site, and cultivars Strawberry Festival, Sweet Charlie, Treasure, and Winterstar™ (FL 05-107) had the smallest fruit diameter. Overall, for all locations, 'Benicia' and 'Camino Real' had the largest fruit diameter and 'Strawberry Festival' had the smallest fruit diameter. 'Albion' fruit diameter was larger at Virginia Beach and Chesapeake sites but their fruit diameter was slightly smaller relative to the other cultivars at Westmoreland County site.

The flavor of strawberries is dependent on TSS and aroma-active compounds, both of which can vary significantly at each harvest (Pozo-Insfran et al., 2006). The TSS can be influenced by the interaction of numerous factors, including light intensity, soil and plant moisture content, fertility, and leaf to fruit ratio (Cao et al., 2015; Carlen et al., 2007; Choi et al., 2014). Due to the

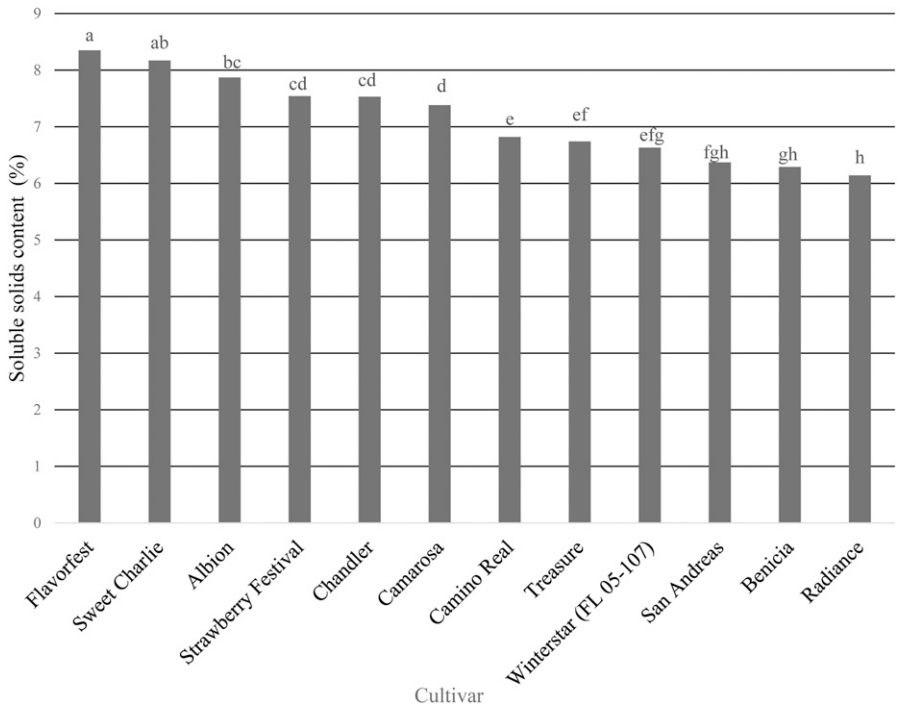

Fig. 1. Cultivar effect on average total soluble solids concentration of selected strawberry cultivars over the harvest season pooled over locations. Means with the same letter are not significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

complexity in understanding these factors for each location, we ran our statistical analysis on TSS readings averaged across the harvest season. We provide the range of TSS concentration values in Table 7. The average TSS concentration for the season was influenced only by cultivars. 'Flavorfest' had the highest TSS content, although not different from 'Sweet Charlie' (Fig. 1). Lewers et al. (2017) reported a higher TSS averaging 7.7% for 'Flavorfest' over 7.3% for 'Chandler' from multiyear trials in Beltsville, MD. This is consistent with our findings of an average TSS across all locations of 8.4% for 'Flavorfest' over 7.5% for 'Chandler'. 'Sweet Charlie' is an early fruiting short-day cultivar and is known for its sweet flavor (Chandler et al., 1997). In a trial involving five short-day cultivars, Sweet Charlie and Strawberry Festival had the highest TSS content under conventional production systems, although the differences among cultivars were not always statistically different (Macit et al., 2007).

Our findings indicate that 'Benicia' and 'Camino Real' can yield as well in different locations, production practices, and soil types of southeastern Virginia as 'Chandler' and 'Camarosa', the two most commonly grown cultivars in Virginia. Relative to 'Chandler' and 'Camarosa', 'Benicia' is a more recent cultivar released by the University of California and is marketed for its high yield and large fruit (Gasic and Preece, 2014). 'San Andreas' and 'Albion' seem to be promising day-neutral cultivars, although we could not evaluate their full potential in our trials, as we treated them like short-day cultivars. To evaluate the true potential of day-neutral cultivars, and determine their fall-bearing potential, they need to be transplanted in fruiting fields by the first week in September and getting plug plants that early can be challenging for Virginia fruit producers. Moreover, the objective of our study was to determine alternative cultivars to Chandler and Camarosa that growers can adopt in coastal Virginia, with little change to existing cultural practices. 'Flavorfest' and 'Sweet Charlie' produced berries with high TSS, offering additional marketing opportunities for direct consumer markets.

Our findings of this study were mostly similar to those by Gu et al. (2017), and our regional cultivar recommendations are similar to North Carolina Cooperative Extension (2020). Although, in a cultivar trial study in North Carolina, 'Camarosa' did not yield as well as 'Benicia', 'Camino Real', and 'Chandler', perhaps due to plant loss from disease incidences (North Carolina Cooperative Extension, 2015). Findings from this Virginia cultivar evaluation study have been disseminated at preplant meetings in Virginia and the Southeast Strawberry Expo in Pinehurst, NC, in 2014. As a result, there has been a strong interest in 'Camino Real' in the mid-Atlantic and south-Atlantic region of the United States. Growers describe 'Camino Real' fruit to be good tasting and this cultivar can withstand rain in open-field conditions. 'Flavorfest' has also seen an increase in interest among growers in the mid-Atlantic region of the United States during this time due to its flavor attributes. 'Benicia', despite its high-yield attribute, lacks in flavor, an important trait for local food markets. Strawberry breeding influences response of cultivars to fertilization practices and additional work in determining optimum fertilizer doses for cultivar and type is needed for the south-Atlantic region (Dixon et al., 2019; Santos and Chandler, 2009). Findings from this study have helped with diversification of strawberry cultivars at farm level. This has implications for improved sustainability for locally grown food.

Literature cited

Antunes, L.E.C., N.C. Ristow, A.C.R. Krolow, S. Carpenedo, and C. Reisser, Jr. 2010. Yield and quality of strawberry cultivars. Hort. Bras. 28:222–226.

Ballington, J., B. Poling, and K. Olive. 2008. Day-neutral strawberry production for season extension in the Midsouth. HortScience 43:1982–1986.

Cao, F., C. Guan, H. Dai, X. Li, and Z. Zhang. 2015. Soluble solids content is positively correlated with phosphorus content in ripening strawberry fruits. Scientia Hort. 195:183–187.

Carlen, C., A.M. Potel, and A. Ancay. 2007. Influence of leaf/fruit ratio of strawberry plants on the sensory quality of their fruits. Acta Hort. 761:121–126.

Chandler, C.K., E.E. Albregts, C.M. Howard, and J.K. Brecht. 1997. 'Sweet Charlie' strawberry. HortScience 32: 1132–1133.

Choi, H.G., B.Y. Moon, N.J. Kang, J.K. Kwon, K. Bekhzod, K.S. Park, and S.Y. Lee. 2014. Yield loss and quality degradation of strawberry fruits cultivated under the deficient insolation conditions by shading. Hort. Environ. Biotechnol. 55:263–270.

Christman, J. and J.B. Samtani. 2019. A survey of strawberry production practices in Virginia. Virginia Coop. Ext. Publ. SPES-150.

Dixon, E., B. Strik, J. Fernandez-Salvador, and L. Devetter. 2019. Strawberry nutrient management guide for Oregon and Washington. Oregon State Univ. EM 9234. 10 June 2020. <https://catalog.extension.oregonstate.edu/em9234/html>.

Gasic, K. and J.E. Preece. 2014. Register of new fruit and nut cultivars list. HortScience 49:396–421.

Gu, S., W. Guan, and J.E. Beck. 2017. Strawberry cultivar evaluation under high-tunnel and organic management in North Carolina. HortTechnology 27:84–92.

Hokanson, S.C. and C.E. Finn. 2000. Strawberry cultivar use in North America. HortTechnology 10:94–106.

Kaps, M.L., M.B. Odeneal, and P.L. Byers. 2003. Strawberry cultivar performance in Missouri. J. Amer. Pomol. Soc. 57:19–25.

Lewers, K., P. Castro, J. Enns, S.C. Hokanson, G.J. Galletta, D.T. Handley, A.R. Jamieson, M.J. Newell, J.B. Samtani, R.D. Flanagan, B.J. Smith, J.C. Snyder, J.G. Strang, S.R. Wright, and C. Weber. 2017. 'Flavorfest' strawberry. HortScience 52:1627–1632.

Lopez-Medina, J., E. Vazquez, J.J. Medina, F. Dominguez, J.M. Lopez-Aranda, R. Bartual, and F. Flores. 2001. Genotype x environment interaction for planting date and plant density effects on yield characters of strawberry. J. Hort. Sci. Biotechnol. 76:564–568.

Macit, I., A. Koc, S. Guler, and I. Deligoz. 2007. Yield, quality and nutritional status of organically and conventionally-grown strawberry cultivars. Asian J. Plant Sci. 6:1131–1136.

Nelson, M.D., W.D. Gubler, and D.V. Shaw. 1996. Relative resistance of 47 strawberry cultivars to powdery mildew in California greenhouse and field environments. Plant Dis. 80:326–328.

North Carolina Cooperative Extension. 2020. Strawberry varieties 2015. 22 Aug. 2020. <https://strawberries.ces.ncsu.edu/strawberries-plasticulture-considerations-varieties/>.

North Carolina Cooperative Extension. 2015. Strawberry yield data 2015. 22 Aug. 2020. <https://strawberries.ces.ncsu.edu/strawberries-research-reports/strawberry-yield-data- 2015/>.

Ortiz, R., J. Crossa, M. Vargas, and J. Izquierdo. 2007. Studying the effect of environmental variable on the genotype x environment interaction of tomato. Euphytica 153:119–134.

Poling, B., G. Krewer, and J.P. Smith. 2005. Southeast regional strawberry plasticulture production guide. 27 Apr. 2020. <https://smallfruits.org/files/2019/06/2005culturalguidepart1bs1.pdf>.

Pozo-Insfran, D.D., C.E. Duncan, K.C. Yu, S.T. Talcott, and C.K. Chandler. 2006. Polyphenolics, ascorbic acid, and soluble solids concentration of strawberry cultivars and selections grown in a winter annual hill production system. J. Amer. Soc. Hort. Sci. 131:89–96.

Purdue University. 2017. Nested factors. 13 May 2020. <http://www.stat.purdue.edu/~bacraig/notes1/topic19.pdf>.

Samtani, J.B., C.R. Rom, H. Friedrich, S.A. Fennimore, C.E. Finn, A. Petran, R.W. Wallace, M.P. Pritts, G. Fernandez, C. Chase, C. Kubota, and B. Bergefurd. 2019. The status and future of the strawberry industry in the United States. HortTechnology 29:11–24.

Samtani, J.B., J.B. Weber, and S.A. Fennimore. 2012. Tolerance of strawberry cultivars to oxyfluorfen and flumioxazin herbicides. HortScience 47:848–851.

Santos, B.M. and C.K. Chandler. 2009. Influence of nitrogen fertilization rates on the performance of strawberry cultivars. Intl. J. Fruit Sci. 9:126–135.

Shaw, D.V. and K.D. Larson. 2002. Strawberry plant named 'Camino Real'. U.S. Plant Patent No. US PP13,079 P2. Filed 7 Feb. 2001. Issued 15 Oct. 2002. 22 Aug. 2020. <https://patents.google.com/patent/USPP13079P2/en>.

Shaw, D.V. and K.D. Larson. 2006. Strawberry plant named 'Albion'. U.S. Plant Patent No. US PP16, 228 P3. Filed 29 Jan. 2004. Issued 31 Jan. 2006. 22 Aug. 2020. <https://patents.google.com/patent/USPP16228P3/en>.

Shaw, D.V. and K.D. Larson. 2008. Performance of early-generation and modern strawberry cultivars from the University of California breeding program in growing systems simulating traditional and modern horticulture. J. Hort. Sci. Biotechnol. 83:648–652.

Torres-Quezada, E.A., L. Zotarelli, V.M. Whitaker, B.M. Santos, and I. Hernandez-Ochoa. 2015. Initial crown diameter of strawberry bare-root transplants affects early and total fruit yield. HortTechnology 25:203–208.

U.S. Department of Agriculture. 2019. 2019 Census of agriculture- state data-Virginia Table 38. 19 June 2019. <https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Virginia/>.

Whitaker, V.M., C.K. Chandler, B.M. Santos, and N.A. Peres. 2013. 'Florida Radiance' strawberry. Univ. Florida Inst. Food Agr. Sci. Ext. HS 1151. 28 July 2019. <http://edis.ifas.ufl.edu/hs400>.