Effect of Plant Population and Breeding Lines on Fresh-market, Compact Growth Habit Tomatoes Growth, Flowering Pattern, Yield, and Postharvest Quality

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Abstract. Compact growth habit (CGH) tomatoes (*Solanum lycopersicum*) are determinate plants with shortened internodes and strong side branching due to the brachytic gene (*br*) that grow either prostrate or upright as a result of unidentified gene(s). Compact growth habit tomatoes do not require staking, tying, or pruning and can potentially be mechanically harvested, lowering Florida fresh-market tomato production costs. Therefore, the objective of this study was to evaluate the effects of two planting configurations (single and double row) and breeding lines (BLs) on CGH tomato plant growth, flowering pattern, yield, and postharvest fruit quality. Two experiments were conducted in Immokalee, FL, during Spring 2013 and 2014 in a split-plot design with four replications. Planting configurations affected CGH tomato growth at midseason in 2013 but not in 2014; however, in 2014, CGH tomato vines grew outside the beds into the row middles, which is uncommon for this tomato type and undesirable. Plants of CGH tomatoes had a similar flowering pattern to a conventional upright tomato cultivar, which was unexpected. Planting configurations did not affect marketable yields in 2013, but single-row plots produced higher extra-large and total marketable yields at first and total season harvests in 2014. Total season marketable harvests ranged from 26.1 to 53.6 and 29.3 to 45.6 Mg·ha⁻¹ in 2013 and 2014, respectively. Fla 8916 was among the highest yielding BLs, maximizing extra-large and total season marketable yields. Unmarketable fruit ranged from 22% to 31% and 25% to 52% of the total season harvest in 2013 and 2014, respectively, and the most common defects were sunscald, off-shape, catface, and graywall. All CGH evaluated may be suitable for mature-green harvest regarding postharvest fruit quality, although fruit ripening uniformity was of concern in 2014. Average CGH total season marketable yields harvested twice were lower than expected yields of staked-upright tomato cultivars that may be harvested three times, but higher than Florida average yields. However, CGH tomato total production cost can potentially be lower than staked-upright cultivars making CGH tomatoes a viable alternative for the Florida mature-green fresh-market industry to remain sustainable.

for the Florida fresh market are hybrids with a determinate upright growth habit that require staking, tying, pruning, and manual harvest. These cultural practices account for as much as 55% of the total tomato production cost (Davis and Estes, 1993), estimated at \$34,595·ha⁻¹ (G. McAvoy, personal communication). Mexico is the main Florida competitor for fresh-market tomatoes in the United States with the ability to produce tomatoes at lower cost per unit, which forces the Florida industry to seek new production systems to reduce cost and/or increase yields and fruit quality (McAvoy and Ozores-Hampton, 2011).

CGH tomatoes, which are determinate plants with a unique architecture, may be the basis of an alternative production system for Florida tomatoes. These tomato plants have low growth and spreading characteristics, forming compact vines that hold fruit above the ground as a result of their short branches and do not require staking, tying, or pruning (Kemble et al., 1994). When in the field, these tomato plants will cover the polyethylene-mulched bed but will not grow into the row middles, holding most of the fruit above the bed surface (Scott et al., 2010). As a result of the plant architecture of CGH tomatoes, they may be grown in a higher plant density than the currently used tomato cultivars, which may recover the losses of vertical space use. Studies with the CGH tomato line NC 13G-1, evaluated in North Carolina, planted in single or double rows showed that higher early and total marketable yields were produced in double rows compared with single rows (Gardner and Davis, 1991; Kemble, 1993). When NC 13G-1 in double rows was compared with the staked-upright tomato ‘Mountain Spring’ (Syngenta, NC) in a single row, NC 13G-1 produced 48% higher yield, although the staked-upright tomato cultivar had higher individual fruit weight than the NC 13G-1 line (Kemble, 1993).

Compact growth habit cultivars that have the jointless pedicel characteristic (*j* or *j-2* genes) may be once-over mechanically harvested, eliminating the need for expensive hand-harvest labor (Scott et al., 2010). Because CGH tomatoes have in general a concentrated fruit set, they can be harvested once or twice (if manually harvested), reducing the harvesting cost when compared with the currently grown staked-upright tomatoes, which are generally harvested three or more times. Production costs would also be reduced because the time from transplant to final harvest in CGH tomatoes may be 2 to 4 weeks shorter than the currently grown cultivars (Ozores-Hampton et al., 2013a).

The development of a concentrated fruit set that is generally early in maturity in CGH plants compared with currently grown staked-upright tomato cultivars (Ozores-Hampton et al., 2013a; Scott et al., 2010) will be critical to enable once-over mechanical harvest (George and Berry, 1992). In processing tomatoes, which are mechanically harvested, plants set fruit and the fruit reaches maturity in a

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Nationally, Florida ranks first in fresh-market tomato (*Solanum lycopersicum*) production value with U.S. \$455 million in the 2013 season [U.S. Department of Agriculture (USDA), 2014]. In 2013, Florida had the largest fresh-market tomato area in the United States with 13,760 ha harvested and an average yield of 29.7 Mg·ha⁻¹ resulting in 408,397 Mg of tomato fruit (USDA, 2014). The majority of the tomato cultivars grown

concentrated time period, which maximizes the harvest while maintaining fruit quality (George and Berry, 1992). For the fresh-market, mature-green tomato industry, a concentrated fruit set will maximize the amount of mature-green fruit at the time of harvest and enable the use of exogenous ethylene application, which is currently used by this industry.

Compact growth habit tomatoes with jointless pedicels that would be commercially acceptable have not been completely developed for the Florida market at this time, but progress is being made by the University of Florida Tomato Breeding Program (UF/TBP). Evaluation of the performance of new CGH tomato BLs and appropriate cultural practices to maximize yields at different locations will be crucial in the process of selecting lines that are suitable for the target market. Therefore, the objective of this study was to evaluate the effects of two planting configurations (single and double row) and BL on CGH tomato growth, flowering pattern, yield, and postharvest quality.

Materials and Methods

Two experiments were conducted on a commercial farm in Immokalee, FL, during Spring 2013 and Spring 2014. On 12 Nov. 2012 and 21 Nov. 2013, beds were formed 1.8 m center to center, being 20 cm high in the middle, 18 cm high on the edges, and 81 cm wide. After bed formation, beds were fertilized, fumigated with 1,3-dichloropropene and chloropicrin (40:60) at a rate of 123 and 134 kg-ha⁻¹ in 2013 and 2014, respectively (Interagro, FL), and covered with virtually impermeable film, black in 2013 and metallized in 2014 (TriEst Ag Group, NC). In both years, pre-plant dry fertilizer was broadcast as a “bottom mix” and applied on two fertilizer bands on the bed shoulders as the “top mix” (Olson et al., 2010) for a total nitrogen-phosphorus-potassium (N-P-K) of 207–49–344 kg-ha⁻¹. Sources of dry fertilizer were ammonium nitrate, triple superphosphate, and potassium sulfate plus micronutrients. Fertigation was used to supplement the pre-plant fertilizer with 112–0–167 kg-ha⁻¹ N-P-K from tomato flowering to first harvest. The polyethylene-mulched beds slope was modified from 70.4° to 63.4° or 10% steeper slope manually by rolling a polyvinyl chloride pipe on the shoulders of the beds to enable improved drainage.

In 2013, six CGH tomato BLs (Fla 8914, Fla 8915, Fla 8916, Fla 8916a, Fla 8916b, and Fla 8834) from the UF/TBP were planted with two planting configurations (PCs), as single and double rows. In 2014, the CGH BL Fla 8924 and the normal growth habit, upright tomato cultivar Florida-47 (FL 47) (Seminis Vegetable Seeds, Inc., MO) were planted in addition to the six BLs evaluated in the previous year. All CGH BLs have the jointless (*j2*) gene, the light green shoulders (*u*) gene, and produce flat, round tomato fruit. Tomato seedlings were planted on 18

Dec. 2013 and 19 Dec. 2014 as 6-week-old transplants grown in 200-cell Styrofoam trays produced by Redi Plants Corp. (Naples, FL). Plots were 6 m long, composed of 10 plants for single-row and 14 plants for double-row plots. Single-row plots had an in-row spacing of 61 cm (9108 plants/ha) and double rows were planted in an alternated pattern with a diagonal spacing between plants of 48 cm (11,575 plants/ha). Plants in the double-row arrangement were located 15 cm from the dry fertilizer band on the bed shoulders and the drip irrigation tape was moved to the middle of the bed between the two tomato rows. Tomato plants were not staked, tied, or pruned. The experimental design was a split plot with four replications, where PCs were the main plots and the BLs were the sub-plots. The crop was irrigated by a hybrid system of seepage (Ozores-Hampton et al., 2012a) and drip irrigation, which allowed for fertigation. Pesticide applications were performed as needed according to regular scouting reports and UF/IFAS recommendations (Santos et al., 2013).

Tomato plant growth was measured as plant height (H), canopy diameter along the bed length (D1), and canopy diameter across the bed length (D2) at 60 and 90 d after transplanting (DAT) in 2013 and at 30, 60, and 90 DAT in 2014. Plant volume (V) was calculated as $H \times D1 \times D2$. Flowering data were recorded in 2014 from single-row plots of Fla 8915, Fla 8916, and ‘FL 47’. The six central plants of each BL/cultivar were used for non-destructive data collection throughout the flowering period in a randomized complete block design with four replications. The number of open flowers in the first flower cluster was recorded three times from 18 Jan. (30 DAT) to 28 Jan. 2014, and the number of flower clusters with open flowers per plant was counted seven times from 18 Jan. to 14 Feb. 2014. The data collected were used to calculate the number of days from transplanting to first open flower and the number of days from first open flower to first harvest (FH).

Tomato fruit were manually harvested at the mature-green stage on 19 Mar. (91 DAT) and 3 Apr. 2013 (106 DAT) and on 31 Mar. (102 DAT) and 14 Apr. 2014 (116 DAT). Fruit were graded into marketable sizes and weighed separately according to the USDA specifications for extra-large (greater than 7.00 cm), large (6.35 to 7.06 cm), and medium (5.72 to 6.43 cm) (USDA, 1997). Unmarketable fruit weight was categorized and recorded according to the presence of sunscald, off-shape, and other defects (scratch and graywall) in 2013 and sunscald, off-shape, catface, and graywall in 2014 (Jones et al., 1991; Ozores-Hampton et al., 2010). At the first harvest, a sub-sample of 20 mature-green tomato fruit per plot was collected, placed in labeled paper bags, and transported to the Gargiulo, Inc. packing house (Immokalee, FL), where fruit were subjected to ethylene treatment at 20 °C and 85% to 90% relative humidity until Stage 2 of ripeness (breaker) (Sargent et al., 2005; USDA, 1997). After tomatoes achieved

Stage 2, they were transported to the University of Florida Southwest Florida Research and Education Center (UF/SWFREC) Vegetable Horticulture Laboratory in Immokalee, FL, and ripened at room temperature (23 to 24 °C) until the table-ripe stage for post-harvest evaluations (Ozores-Hampton et al., 2010). Four fruit from each plot were measured for firmness as fruit deformation using an 11-mm probe and 1-kg force applied to the fruit equator area for 5 s using a portable digital firmness tester (Model C125EB; Mitutoyo, Corp., Aurora, IL). Exterior fruit color was measured on the same four fruit using a 1 to 6 scale where 1 = green and 6 = red (USDA, 1997). Total soluble solids (TSS) and pH analysis were performed using one-fourth of each of the four fruit. The samples were frozen in sealed poly bags at –30 °C and later were thawed, homogenized, and centrifuged (Model Sorval ST16; Thermo Scientific, Waltham, MA) at 7177 g_n for 20 min. The supernatant was filtered through cheesecloth and the filtrate was used to measure TSS and pH with a portable refractometer (Model Eclipse 45-02; Bellingham + Stanley Inc., Suwanee, GA) at 20 °C and a pH meter (Model 420A; Orion Research Inc., Boston, MA), respectively. Plant growth, marketable and unmarketable fruit yields, fruit firmness, exterior color, TSS, and pH were analyzed separately by year. All data, except for flowering, were analyzed by analysis of variance using the PROC GLIMMIX procedure in SAS (SAS 9.2; SAS, 2011) with PC and BL being fixed variables, whereas replication was the random variable. Least square means were separated by Tukey-Kramer honestly significant difference test at the 95% confidence level. When interactions between PC and BL (PC × BL) were significant, least square means separation was performed for each PC and BL combination. Flowering data were analyzed using the PROC GLM procedure in SAS and means were separated by the Duncan’s multiple range test at the 95% confidence level.

Results and Discussion

Weather conditions. Overall, in 2013, weather conditions were average for southwest Florida during the spring season based on 14 years of data recorded by the Florida Automated Weather Network (Table 1); however, in 2014, average air temperatures were ≈1.9 °C higher and accumulated rainfall was 56 mm greater when compared with the 14-year average for Immokalee, FL.

Tomato plant growth in Spring 2013 and 2014. In 2013, PC × BL interactions were not significant for V at 60 and 90 DAT (Table 2). The single row had higher V than the double row at 60 DAT ($P = 0.0001$); however, no differences between PCs were found at 90 DAT. No differences among CGH lines were found in 2013 and average V was 169.4 and 249.7 dm³ at 60 and 90 DAT, respectively. In 2014, PC × BL interactions were significant for V at 30 DAT but not at 60 or 90 DAT. At 30 DAT, V ranged from 12.8 to 38.7 dm³ in

Table 1. Summary of minimum, mean, and maximum daily average air temperatures and total rainfall during Spring 2013, 2014, and 14-year spring averages for Immokalee, FL.

Period	Temperature (°C)			Total rainfall (mm)
	Minimum	Mean	Maximum	
Spring 2013				
December ^z	8.1	16.4	25.5	4.57
January	13.4	19.6	27.9	4.06
February	11.3	18.7	27.2	59.18
March	8.5	16.8	25.6	61.47
April	16.1	22.5	31.3	14.73
Average/total	11.5	18.8	27.5	144.02
Spring 2014				
December	16.0	21.1	28.0	0.51
January	10.0	16.4	23.7	97.54
February	13.3	20.3	28.9	27.69
March	12.3	19.9	27.9	58.17
April	14.5	22.2	30.9	15.75
Average/total	13.2	20.0	27.9	199.64
Spring 14-year average				
Average/total	10.8	18.1	26.4	143.80

^aThe temperature averages and rainfall totals were recorded daily from 19 Dec. 2012 and 18 Dec. 2013 through 3 Apr. 2013 and 14 Apr. 2014.

Data source: Florida Automated Weather Network (<<http://fawn.ifas.ufl.edu/>>).

Table 2. Plant volume at 30, 60, and 90 d after transplanting (DAT) for compact growth habit tomato breeding lines (BLs) grown during Spring 2013 and 2014 in Immokalee, FL.

	2013			2014		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
	(dm ³)					
PC × BL ^a	—	NS	NS	***	NS	NS
PC ^b	—					
Single	—	194.4 a ^{x,w}	263.2	—	196.2	230.8
Double	—	145.8 b	236.7	—	183.1	203.9
P value	—	0.0001	0.39	—	0.38	0.35
Significance ^c	—	***	NS	—	NS	NS
BL/cultivar	—			S	D	
Fla8914	—	168.2	262.7	26.3 ab	20.6	204.1 ab
Fla8915	—	184.7	252.4	12.8 b	24.9	153.6 b
Fla8916	—	169.1	239.1	15.4 b	19.2	182.4 ab
Fla8916a	—	168.9	265.9	17.2 b	23.7	189.7 ab
Fla8916b	—	1633	225.7	16.8 b	22.5	180.5 ab
Fla8834	—	162.5	252.5	38.7 a	22.9	184.4 ab
Fla8924	—	—	—	18.9 b	31.8	192.6 ab
FL47	—	—	—	36.6 a	28.9	236.6 a
P value	—	0.79	0.81	0.0001	0.27	0.004
Significance	—	NS	NS	***	NS	**

^aPC × BL = interaction between planting configuration and BL. When interactions were significant least square means separation was performed separately for each PC and BL.

^bPC = planting configuration.

^cPlant volume = H × D1 × D2.

^wWithin columns (a, b) and rows (*), means followed by different letters are significantly different according to Tukey-Kramer honestly significant difference test at 5%.

^xNS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

the single row with 'FL 47' and Fla 8834 having greater V than all CGH except Fla 8914 ($P = 0.0001$). No differences occurred in the double row, which averaged 24.2 dm³. At 60 DAT, V ranged from 153.6 to 236.6 dm³ and 'FL 47' had larger plants than Fla 8915 ($P = 0.004$). At 90 DAT, no differences among CGH and 'FL 47' were found and V averaged 216.6 dm³.

In 2013, the single row had higher V than the double row at 60 DAT. Plants in the single-row arrangement may have had less competition for space and thus growth was greater than plants in the double row. These differences were not observed at the end of the growing season because at 90 DAT, plants had stopped the vegetative growth

and filled the bed surface, thus reducing the competition for space. Typically, vines of CGH tomatoes when fully grown will cover the polyethylene-mulched bed but will not grow into the row middles, holding most of the fruit above the bed surface (Scott et al., 2010). However, in 2014, CGH plants' average diameter across the bed length at 60 and 90 DAT (71.6 and 73.6 cm, respectively) was considerably higher than in 2013 (52.9 and 57.3 cm, respectively) (data not shown) with the vines growing outside the bed surface. This type of growth is undesirable because farm machinery may run plants over during pesticide applications, leaves will be more exposed to soil pathogens, and fruit will be subject to decomposition by soil pathogens

and sustain epidermis sand damage. In 2014, minimum temperatures between 25 and 35 DAT were in average 5 °C lower than in 2013 and night temperatures below 12.8 °C occurred for more than 4 consecutive days, which can cause tomato flower drop, and consequently plants may relocate carbohydrates toward vegetative growth instead of reproductive growth (Mills, 1988; Ozores-Hampton et al., 2012b). Therefore, the atypical growth of CGH tomato vines in 2014 may have been the result of the 2014 lower night temperatures.

Tomato flowering pattern. There were no significant differences in the number of flowers in the first cluster and in the number of clusters with open flowers on any of the sampling dates [$P \geq 0.05$ (Table 3)]. The average number of days from transplanting to first open flower was 41, 43, and 42 for Fla 8915, Fla 8916, and 'FL 47', respectively (data not shown). The number of days from first open flower to FH was 61, 59, and 60 for Fla 8915, Fla 8916, and 'FL 47', respectively (data not shown).

Compact growth habit BLs required a similar time to have first open flower than 'FL 47', a mid- to main-season tomato cultivar (Semini, 2014). This indicates that the more concentrated fruit set attributed to CGH tomatoes (Scott et al., 2010) may not be related to the earliness of the first open flower. The number of clusters with open flowers was measured to investigate the concentration of fruit set of CGH. In this study, the flowering pattern of the CGH BL was not more concentrated than the flowering pattern of 'FL 47'. Although unexpected, this finding may be the result of high N fertilizer rate, which can potentially decrease early yields of tomato and generally delays maturity of fruit crops (Johnson, 2012; Kaniszewski et al., 1987). Plants of CGH tomatoes may be more sensitive to N fertilization than staked-upright tomatoes (Ozores-Hampton et al., 2013a) and the N rate used in the study (319 kg·ha⁻¹) may have been higher than adequate for this tomato type. Research with California bush tomatoes, which are genetically different from CGH but have compact plant architecture, has shown that maximum yields may be obtained with 112 to 202 kg·ha⁻¹ N with drip irrigation under normal conditions (Le Strange et al., 2000). However, California growers may apply 140 to 280 kg·ha⁻¹ N for bush-grown tomatoes (Le Strange et al., 2000). N rate recommendations for CGH tomatoes cultivated in Florida are still not available and further research on the matter is needed; thus, N rates used in the present study reflect common cultural practices of Florida tomato growers. The number of days from transplanting to first open flower and from first open flower to FH was not different between CGH BL and 'FL 47', reflecting the flowering patterns evaluated, which may also be attributed to the N fertilization used.

Tomato marketable fruit yields in Spring 2013 and 2014. In 2013, interactions PC × BL were not significant for any of the yield size categories or harvests, except for large fruit at second harvest (SH) (Table 4). In 2013, PC

Table 3. Number of open flowers in the first cluster and number of clusters with open flowers for compact growth habit tomato breeding lines (BLs) and normal growth habit tomato 'FL 47' grown during Spring 2014 in Immokalee, FL.

Breeding line/cultivar	Number of open flowers in the first cluster			Number of clusters with open flowers						
	Days after transplant			Days after transplant						
	30	36	40	30	36	40	46	50	54	57
Fla8915	0.08	0.67	1.00	0.08	0.33	0.54	1.46	4.21	8.75	12.56
Fla8916	0.13	0.29	0.88	0.08	0.17	0.46	1.54	4.63	9.29	12.21
FL47	0.00	0.00	0.79	0.00	0.00	0.58	1.92	6.17	10.71	14.46
<i>P</i> value	0.18	0.10	0.91	0.13	0.13	0.85	0.55	0.22	0.63	0.60
Significance ^z	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^zNS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 4. Marketable fruit yields by size categories at first, second, and total season marketable harvest (first and second harvests combined) for compact growth habit tomato breeding lines (BLs) grown during Spring 2013 and 2014 in Immokalee, FL.

	Yield (Mg·ha ⁻¹)											
	First harvest				Second harvest				Total season marketable harvest			
	T ^z	XL	L	M	T	XL	L	M	T	XL	L	M
<i>Spring 2013</i>												
PC × BL ^y	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
PC ^x												
Single	22.06	10.33	6.84	4.89	18.7	1.4	—	13.1	40.8	11.7	11.1	18.0
Double	24.81	11.80	7.42	5.59	19.6	1.4	—	13.5	44.4	13.3	12.1	19.1
<i>P</i> value	0.19	0.32	0.35	0.23	0.30	0.63	—	0.67	0.11	0.27	0.09	0.34
Significance ^w	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS	NS
BL/cultivar							S	D				
Fla8914	16.2 c ^v	4.7 d	6.6 bc	5.0 b	25.0 a	1.5 bc	5.5 ab	18.3 a	18.1 a	41.3 c	6.2 d	12.0 bc
Fla8915	30.9 a	11.0 c	10.6 a	9.3 a	22.7 a	1.0 bc	5.1 ab	5.0 a	16.7 a	53.6 a	11.9 c	15.7 a
Fla8916	30.0 a	17.7 a	7.8 b	4.5 b	18.4 bc	1.7 ab	3.8 bc	5.0 a	12.3 b	48.4 ab	19.4 a	12.2 bc
Fla8916a	24.0 b	13.1 bc	6.6 bc	4.3 b	20.9 ab	2.4 a	7.1 a	5.6 a	12.2 b	45.0 bc	15.5 b	13.0 ab
Fla8916b	25.5 b	14.5 b	6.0 bc	4.9 b	15.7 cd	1.3 bc	2.6 cd	4.4 ab*	10.9 b	41.2 c	15.8 b	9.5 cd
Fla8834	13.9 c	5.4 d	5.1 c	3.4 b	12.1 d	0.7 c	1.3 d	2.3 b	9.6 b	26.1 d	6.2 d	6.9 d
<i>P</i> value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.002	0.0001	0.0001	0.0001	0.0001
Significance	***	***	***	***	***	***	***	**	***	***	***	***
<i>Spring 2014</i>												
PC × BL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PC												
Single	23.0 a	7.3 a	7.2	8.4	19.6 a	1.5	5.3	12.7 a	41.3 a	8.4 a	12.1	20.7 a
Double	18.5 b	4.9 b	6.1	7.6	14.9 b	1.2	3.6	10.2 b	33.4 b	6.1 b	9.6	17.8 b
<i>P</i> value	0.05	0.03	0.16	0.53	0.0001	0.24	0.07	0.005	0.007	0.001	0.09	0.01
Significance	*	*	NS	NS	***	NS	NS	**	**	***	NS	**
BL/cultivar												
Fla8914	16.4 cd	2.8 c	4.7 cd	8.9	20.9 a	0.9 ab	4.4 ab	15.6 a	37.3 ab	3.7 c	9.1 c	24.5 a
Fla8915	16.6 bcd	2.4 c	5.4 bcd	8.8	17.2 ab	0.6 b	4.4 ab	12.3 ab	31.5 b	2.5 c	9.0 c	19.9 ab
Fla8916	26.0 a	8.7 ab	8.5 a	8.8	19.6 a	2.5 a	5.9 a	11.1 ab	45.6 a	11.2 a	14.5 a	19.9 ab
Fla8916a	22.2 ab	8.3 ab	7.2 ab	6.7	17.4 ab	1.7 ab	5.3 a	10.4 b	36.6 ab	8.7 ab	11.6 abc	16.3 b
Fla8916b	26.8 a	8.7 ab	9.0 a	9.1	19.0 a	1.7 ab	5.1 a	12.3 ab	45.8 a	10.4 ab	14.1 ab	21.4 ab
Fla8834	12.5 d	2.1 c	4.3 d	6.1	16.9 ab	1.1 ab	3.5 ab	12.3 ab	29.4 b	3.2 c	7.8 c	18.4 ab
Fla8924	22.1 abc	6.4 b	7.2 abc	8.6	11.2 b	0.2 b	2.2 b	8.7 b	33.3 ab	6.7 bc	9.4 bc	17.3 b
FL47	23.4 a	9.4 a	7.0 abc	7.4	15.9 ab	2.3 a	4.9 ab	8.7 b	39.3 ab	11.7 a	11.8 abc	16.1 b
<i>P</i> value	0.0001	0.0001	0.0001	0.15	0.003	0.0009	0.004	0.001	0.001	0.0001	0.0002	0.004
Significance	***	***	***	NS	**	***	**	***	***	***	***	**

^TT = total; XL = extra-large (greater than 7.00 cm); L = large (6.35 to 7.06 cm); M = medium (5.72 to 6.43 cm).

^yPC × BL = interaction between planting configuration and BL. When interactions were significant least square means separation was performed separately for each PC and BL.

^xPC = planting configuration; S = single row; D = double row.

^wNS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

^vWithin columns (a, b) and rows (*), means followed by different letters are significantly different according to Tukey-Kramer honestly significant difference test at 5%.

had no effect on any of the yield size categories or harvests. First harvest accounted for 39% to 64% of the total season marketable harvest (TSMH) (first and second harvests, all sizes combined) and ranged from 13.9 to 30.9 Mg·ha⁻¹. The highest first total marketable harvest (FTMH) (all size categories combined) were from Fla 8915 and 8916, whereas the lowest were from Fla 8914 and 8834. Second total marketable harvest (STMH) ranged from 12.1 to 25.0 Mg·ha⁻¹ and extra-large fruit yields decreased substantially compared with the FH. Total season marketable harvest ranged from

26.1 to 53.6 Mg·ha⁻¹ and was higher for Fla 8915 and 8916 than Fla 8914, 8916b, and 8834, the latter having the lowest yield. The highest extra-large fruit yield at FH and TSMH was from Fla 8916 ($P = 0.0001$).

In 2014, interactions PC × BL were not significant for any of the yield size categories or harvests. The single row had higher FTMH and extra-large fruit at FH, STMH and medium fruit at SH, and TSMH, extra-large, and medium fruit yields than the double row ($P \leq 0.05$). First total marketable harvest accounted for 42% to 65% of the TSMH ranging from

12.5 to 26.8 Mg·ha⁻¹. Fla 8916, 8916b, and 'FL 47' had higher FTMH than Fla 8914, 8915, and 8834 ($P = 0.0001$). Extra-large fruit yield at FH was higher for 'FL 47' than for Fla 8914, 8915, 8834, and 8924 ($P = 0.0001$). Fla 8914, 8916, and 8916b had higher STMH than Fla 8834, which ranged from 11.2 to 20.9 Mg·ha⁻¹ ($P = 0.003$) and extra-large fruit yields decreased in the SH compared with the FH similar to 2013. Total season marketable harvest ranged from 29.4 to 45.6 Mg·ha⁻¹ and was higher for Fla 8916 and 8916b than Fla 8915 and 8834. Fla 8916 and 'FL47' had

higher extra-large fruit yields than Fla 8914, 8915, 8834, and 8924 ($P = 0.0001$).

In 2013, PC did not affect yields of any size category in the FTMH, STMH, and TSMH. These results are in agreement with the findings of Mullins and Straw (1991), which reported plant populations ranging from 7310 to 12,078 plants/ha to have little effect on productivity of staked tomatoes. In 2014, the single row produced higher extra-large and FTMH, medium and STMH, and extra-large, medium, and TSMH than the double row. The lower yields obtained in the double row in the present study contradict the findings of Gardner and Davis (1991) and Kemble et al. (1994) that reported higher early and total marketable yields in double-row plots with the CGH line NC 13G-1. These differences may be attributed to the BLs evaluated and the climate conditions of both regions.

Tomato market price premiums increase with greater tomato size (Bierlen and Grunewald, 1995); therefore, extra-large fruit will be the grower's preferred size category. Fla 8916 was among the highest extra-large fruit producers in both years, being a potential BL to advance in the UF/TBP. First total marketable harvest ranged from 13.9 to 30.9 and 12.5 to 26.8 Mg·ha⁻¹ in 2013 and 2014, respectively. Yields of CGH BL evaluated by Hutton et al. (2013) on a single harvest in Florida ranged from 13.7 to 41.5 Mg·ha⁻¹. Ozores-Hampton et al. (2013b) reported that staked-upright tomato cultivars' average yield at FTMH during two spring seasons ranged from 20.4 to 43.2 Mg·ha⁻¹ in Florida. Therefore, yields of the best producing CGH at FTMH in the present study were lower than the maximum obtained by Hutton et al. (2013) and by Ozores-Hampton et al. (2013b). Differences in the results of Hutton et al. (2013) and the present study may be explained by the high N fertilizer rate used in the latter and the low night temperatures between 25 and 35 DAT. High N fertilizer application can favor vegetative growth over reproductive growth, which may delay and/or reduce fruit formation and consequently decrease yields (Johnson, 2012). Fla 8916 was among the highest FTMH in both years, indicating its potential to maximize extra-large fruit and FTMH in Florida, whereas Fla 8834 was among the lowest yielding BL. These results are similar to the findings of Hutton et al. (2013) in which Fla 8916 had the highest TSMH compared with Fla 8914 and 8834 harvested once and grown during the spring season.

One of the most desirable characteristics of CGH tomatoes is the concentrated fruit set that will potentially enable once-over mechanical harvest or fewer hand-harvests compared with staked-upright tomatoes. First harvest accounted for 39% to 64% and 45% to 65% of the TSMH in 2013 and 2014, respectively. These percentages were within the range that would be expected for commercially available staked-upright tomato cultivars grown in the spring in Florida (50% to 60%) (Ozores-Hampton et al., 2013b). However, as a result of the concentrated fruit set attributed to CGH tomatoes (Scott et al., 2010), this tomato type would be

expected to yield a higher percentage of fruit in the FH, which may have been a consequence of the N rate used.

Once-over mechanical harvest of CGH tomatoes is the ultimate goal of the UF/TBP. Thus, at FH, all size categories were harvested to maximize FTMH yields. Nonetheless, SH was performed to investigate potential yields if CGH plants are hand-harvested twice. In both years, STMH was lower than FTMH with a substantial reduction of extra-large fruit. However, if market prices for large and medium tomatoes are highly favorable, growers may have the option of harvesting twice.

The TSMH yields obtained in the study (Table 4) may be considered acceptable for CGH within the literature (Kemble et al., 1994). Compact growth habit BL NC 13G-1 grown in North Carolina, on a single-row planting with in-row spacing of 61 cm, produced 36.8 Mg·ha⁻¹ of Stage 2 to 6 fruit in the first three harvests and 63.5 Mg·ha⁻¹ in seven harvests (Kemble et al., 1994). In 2014, 'FL 47' FTMH and STMH were among the highest yields obtained in the study. However, this result was not expected because 'FL 47' was grown without staking, tying, and pruning, typical production practices in Florida. Observational yield data from another UF/IFAS experiment, conducted in the same farm with similar production practices, showed that TSMH of the staked-upright commercial cultivar HM 8849 CR (Harris Moran Seed Company, CA) obtained in three harvests was 94.4 and 83.7 Mg·ha⁻¹ in 2013 and 2014, respectively (Shukla and Holt, unpublished data). The TSMH of the best yielding CGH in the present study was lower than 'HM 8849 CR' in both years but higher than the Florida average yield of 29.68 Mg·ha⁻¹ (USDA, 2014). If total production costs of CGH tomatoes are substantially lower than staked-upright cultivars and when farm labor is scarce for harvesting, CGH tomatoes may be a viable option for the Florida mature-green fresh-market industry. Moreover, the compact plant architecture of CGH tomatoes may require lower N fertilizer rate application than currently grown staked-upright tomatoes, which could possibly increase yields and further decrease production costs. Additionally, CGH BLs evaluated in this study are prototypes of the UF/TBP and characteristics such as yield may still be improved before the final cultivars are released to the Florida tomato industry.

Unmarketable fruit yield in Spring 2013 and 2014. In 2013, interactions PC × BL were not significant for total unmarketable (TU) fruit in any of the harvests (Table 5). However, interactions were significant for sunscald and off-shape at SH and total season harvest (TSH). Planting configuration had no effect on TU and fruit defect categories. Total unmarketable at FH, SH, and TSH, as a percentage of the total fruit harvested, ranged from 17% to 29%, 23% to 34%, and 22% to 31%, respectively. At FH and SH, the majority of the fruit defects for CGH were off-shape and sunscald, respectively. In 2014, interactions PC × BL were significant only for TU at TSH. Planting configuration

had no effect on TU and fruit defect categories. Total unmarketable at FH, SH, and TSH, as a percentage of the total fruit harvested, ranged from 24% to 51%, 25% to 53%, and 25% to 52%, respectively. The most common fruit defects were sunscald, off-shape, catface, and graywall. At FH and SH, the majority of the defects for CGH was catface, whereas for 'FL 47', defects were more evenly distributed among the categories at the FH and catface and graywall were the most predominant at the SH. Similar to 2013, sunscalded fruit occurrence at SH was higher than at FH for CGH and ranged from 38% to 57%, being the majority of the fruit defects.

Fruit defects can be caused by internal factors such as the presence of jointless genes and/or external factors such as direct sunlight, temperature, rainfall, and high N fertilization (Jones et al., 1991; Olson, 2012). Therefore, the amount of fruit with defects may vary among BL/cultivars as a result of year-to-year temperature and rainfall fluctuations, which may explain the higher percentages of defects in 2014 compared with 2013. Kemble et al. (1994) reported that the CGH line NC 13G-1 had 40% to 49% and 20% to 38% unmarketable fruit in 1991 and 1992, respectively. Total unmarketable fruit ranged 14% to 57% for currently grown staked-upright tomato cultivars in Florida (Ozores-Hampton et al., 2013b). The CGH evaluated in this study produced an average of 26% and 38% unmarketable fruit in 2013 and 2014, respectively, thus an acceptable range compared with other CGH line and staked-upright tomatoes. However, marketable fruit yields could be increased if fruit defects were further reduced, which can potentially be achieved by changing planting dates and/or location where CGH tomatoes may be grown, avoiding certain environmental conditions such as low night temperatures.

The incidence of sunscald on tomato fruit can increase after harvests and heavy rains (Jones et al., 1991; Olson, 2012). Because CGH have bushy plant architecture, the plants were moved and branches were broken during the FH, which may have increased fruit exposure to direct sunlight and heat, possibly explaining the increased percentage of sunscalded fruit at SH. 'FL 47' had the highest percentage of sunscald at FH, which may be the result of the less compact plant architecture, causing greater exposure of the fruit to direct sunlight and heat when plants are not staked and tied. The percentage of TU at TSH relative to the total fruit harvested may be a useful tool in the selection of BL to advance in the breeding program. In 2013, Fla 8914 had the lowest TU relative to total fruit harvested followed by Fla 8916b, 8915, 8916, 8916a, and 8834. In 2014, 'FL 47' had the lowest TU as a percentage of the total fruit harvested followed by Fla 8914, 8916a, 8834, 8915, 8916b, 8916, and 8924. Based on these percentages, Fla 8914 and 8915 had consistently lower TU as a percentage of the total fruit harvested.

Postharvest tomato fruit evaluation in Spring 2013 and 2014. In 2013, no interactions PC × BL were significant for fruit firmness, exterior color, TSS, or pH (Table 6). Plant

Table 5. Total unmarketable (TU) yield and distribution in the categories of sunscald (SC), off-shape (OF), catface (CF), graywall (GW), and other defects (OT) for compact growth habit tomato breeding lines (BLs) grown during Spring 2013 and 2014 in Immokalee, FL.

	First harvest					Second harvest					Total season harvest				
						Spring 2013									
	TU (Mg·ha ⁻¹)	SC	OF	OT		TU (Mg·ha ⁻¹)	SC	OF	OT		TU (Mg·ha ⁻¹)	SC	OF	OT	
PC × BL ^z	NS	NS	NS	NS		NS	*	**	NS		NS	*	*	NS	NS
PC ^y															
Single	6.0	25	54	21		8.4	—	—	25		14.4	—	—	23	
Double	6.3	32	46	19		8.5	—	—	25		14.9	—	—	23	
P value	0.76	0.20	0.26	0.71		0.91	—	—	0.92		0.85	—	—	0.88	
Significance ^x	NS	NS	NS	NS		NS	—	—	NS		NS	—	—	NS	
BL/cultivar															
Fla8914	4 b ^w	11 b	58 a	26 ab		8 b	S	D	S	D	12 c	S	D	D	29 ab
Fla8915	7 ab	33 ab	29 b	38 a		11 a	55 ab	51 ab	12 c	15 b	17 ab	45 ab	21 c	18 b	35 a
Fla8916	7 ab	34 ab	55 a	12 b		9 ab	57 ab	49 ab	18 bc	20 ab	15 abc	49 ab*	30 bc	39 a	21 b
Fla8916a	9 a	24 ab	66 a	11 b		11 a	45 b	54 ab	35 a	27 a	20 a	32 bc	49 a	41 a	16 b
Fla8916b	5 ab	39 a	46 ab	10 b		7 b	68 a	61 a	11 c	19 ab	13 bc	58 a	27 c	30 ab	16 b
Fla8834	6 ab	30 ab	47 ab	23 ab		6 b	44 b	58 ab	39 a*	22 ab	12 c	34 bc	45 ab*	32 ab	21 b
P value	0.02	0.01	0.001	0.0002		0.0001	0.003	0.03	0.0001	0.06	0.0002	0.0003	0.0001	0.0006	0.0007
Significance	*	*	***	***		***	**	*	***	NS	***	NS	***	**	***

						Spring 2014									
	TC (Mg·ha ⁻¹)	SC	OF	CF	GW	TC (Mg·ha ⁻¹)	SC	OF	CF	GW	TC (Mg·ha ⁻¹)	SC	OF	CF	GW
PC × BL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
PC															
Single	14.3	12	37	27	25	11.5	44	18	23	15	—	27	27	25	20
Double	13.3	12	32	25	32	9.5	43	20	22	16	—	25	26	23	25
P value	0.43	0.58	0.13	0.60	0.21	0.1	0.84	0.68	0.60	0.57	—	0.47	0.80	0.27	0.18
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	NS	NS	NS	NS
BL/cultivar															
Fla8914	6 e	9 b	24 d	38 a	29 bc	8 bc	47 ab	9 c	35 a	10 bcd	S	30 ab ^z	15 d	35 a	20 bc
Fla8915	12 cd	6 b	23 d	15 c	56 a	13 a	36 b	8 c	15 c	41 a	15 c	23 b	15 d	15 c	48 a
Fla8916	18 ab	12 b	31 cd	33 ab	25 bc	12 ab	40 b	21 b	21 bc	18 b	26 c	23 b	26 c	29 ab	22 bc
Fla8916a	19 ab	8 b	46 ab	30 abc	17 c	14 a	37 b	26 b	20 bc	16 bc	34 a	22 b	36 ab	25 abc	17 cd
Fla8916b	15 bc	14 b	39 abc	25 abc	22 bc	10 ab	46 ab	22 b	19 bc	13 bc	28 ab	27 b	32 bc	23 bc	18 cd
Fla8834	10 de	12 b	50 a	22 abc	16 c	10 ab	38 b	39 a	22 bc	2 d	24 bc*	24 b	45 a	22 bc	9 d
Fla8924	23 a	10 b	36 bcd	20 bc	34 b	13 a	49 ab	18 bc	18 bc	15 bc	39 a	23 b	30 bc	19 bc	29 b
FL47	8 de	25 a	24 d	23 abc	28 bc	5 c	57 a	8 c	28 ab	7 cd	13 c	38 a	17 d	26 abc	19 cd
P value	0.0001	0.0001	0.0001	0.003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Significance	***	***	***	**	***	***	***	***	***	***	***	***	***	***	***

^zPC × BL = interaction between planting configurations and BL. When interactions were significant least square means separation was performed separately for each PC and BL.

^yPC = planting configuration; S = single row; D = double row.

^xNS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

^wWithin columns (a, b) and rows (*), means followed by different letters are significantly different according to Tukey-Kramer honestly significant difference test at 5%.

Table 6. Postharvest evaluation of tomato fruit firmness (as fruit deformation), skin color at Stage 6 (red color), total soluble solids content, and pH at first harvest for compact growth habit tomatoes breeding lines (BLs) grown during Spring 2013 and 2014 in Immokalee, FL.

	Deformation (mm)	Color (1–6 scale) ^z	Total soluble solids (%)	pH (0–14)	Deformation (mm)	Color (1–6 scale)	Total soluble solids (%)	pH (0–14)
	Spring 2013				Spring 2014			
PC × BL ^y	NS	NS	NS	NS	NS	NS	NS	NS
PC ^x								
Single	2.49	5.93 a ^w	4.31	4.51 a	3.04	5.66	3.99	4.68
Double	2.54	5.79 b	4.31	4.45 b	3.02	5.64	3.96	4.67
<i>P</i> value	0.70	0.05		0.04	0.90	0.79	0.30	0.75
Significance ^v	NS	*	NS	*	NS	NS	NS	NS
BL/cultivar								
Fla8914	2.12 b	5.69	4.48	4.50 a	2.61 b	5.69	4.01 ab	4.69 ab
Fla8915	2.40 ab	5.97	4.23	4.46 ab	3.18 ab	5.78	4.09 ab	4.70 ab
Fla8916	2.46 ab	5.84	4.20	4.51 a	3.04 ab	5.69	3.94 b	4.64 b
Fla8916a	2.65 ab	5.78	4.20	4.52 a	2.98 ab	5.44	3.86 b	4.69 ab
Fla8916b	2.92 a	5.94	4.33	4.50 a	3.17 ab	5.69	3.93 a	4.69 ab
Fla8834	2.54 ab	5.94	4.43	4.40 b	2.96 ab	5.75	3.93 b	4.61 b
Fla8924	—	—	—	—	3.10 ab	5.40	3.85 b	4.62 b
FL47	—	—	—	—	3.26 a	5.78	4.18 a	4.74 a
<i>P</i> value	0.03	0.13	0.08	0.0003	0.05	0.11	0.0002	0.001
Significance	*	NS	NS	***	*	NS	***	***

^z1 = green and 6 = red (USDA, 1997).

^yPC × BL = interaction between planting configuration and BL. When interactions were significant least square means separation was performed separately for each PC and BL.

^xPC = planting configuration.

^wWithin columns (a, b) and rows (*), means followed by different letters are significantly different according to Tukey-Kramer honestly significant difference test at 5%.

^vNS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

configuration had no effect on fruit firmness and TSS, but the single row had higher exterior color rating and pH than the double row ($P = 0.05$ and 0.04, respectively). Fruit firmness ranged from 2.12 to 2.92 mm and Fla 8914 was firmer than Fla 8916b ($P = 0.03$). Exterior color rating and TSS averaged 5.86% and 4.31%, respectively, with no differences among the CGH. The pH was lower for Fla 8834 than the other CGH except for Fla 8915 ($P = 0.0003$).

In 2014, interactions PC × BL were not significant and there were no differences in PC for any of the postharvest attributes evaluated. Fruit firmness ranged from 2.61 to 3.26 mm with Fla 8914 being firmer than 'FL 47' ($P = 0.05$). There were no differences in exterior color rating, which averaged 5.65. For TSS, Fla 8916b and 'FL 47' had higher contents than Fla 8916, 8916a, 8834, and 8924 ($P = 0.0002$). The pH was lower for Fla 8916, 8834, and 8924 than for 'FL 47' ($P = 0.001$).

Firm fruit and uniform exterior color are the two most important quality attributes that buyers and consumers expect when buying tomatoes (Tijskens and Evelo, 1994). Although in the study there were differences in fruit firmness, in both years, these differences were not of commercial importance because CGH fruit had acceptable firmness. Florida mature-green tomatoes are generally treated with exogenous ethylene, which promotes faster and uniform ripening (Sargent et al., 2005). With more uniform ripening, differences in exterior color at Stages 5 and 6 will be reduced during the ripening process. In 2013, the single row had a higher exterior color rating than the double row. However, all CGH received a rating of 5.4 or higher in both years, indicating that the BLs evaluated would be suitable for mature-green harvest

and subsequent ethylene application based on exterior color development. Total soluble solids are used as indicators of total sugar content in fruits (Cecchi, 1999). Ferreira et al. (2010) reported that fresh-market tomato TSS and pH evaluated in several studies ranged from 4.03% to 5% and 3.87 to 4.38, respectively. In the present study, TSS averages ranged from 4.20% to 4.48% in 2013 and 3.85% to 4.18% in 2014. Fruit TSS is a genetic characteristic of the tomato cultivar and can be influenced by temperature and irrigation (Ferreira et al., 2010). In 2014, TSS averages were lower than in 2013, which was probably the result of slightly higher temperatures and rainfall during the growing season compared with 2013. Although there were significant differences in pH between PC in 2013 and among BL/cultivar in both years, pH values obtained in the study ranged within values reported for whole tomato fruit by the U.S. Food and Drug Administration (4.2 to 4.9) (FDA, 2013). Differences in fruit quality among CGH were not of commercial importance and BLs developed quality characteristics suitable for the mature-green fresh-market in Florida. However, in 2014, tomato ripening uniformity was of concern because a considerable amount of fruit ripened unevenly within samples that were harvested and treated with ethylene in the same date, a characteristic that would be undesirable for the Florida tomato industry.

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