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Under Severe HLB and Citrus Canker Pressure, 'Triumph' and 'Jackson' Perform Better Than 'Flame' and 'Marsh' Grapefruit

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Huanglongbing (HLB) and Citrus Canker (CC) threaten the viability of Florida grapefruit production. 'Triumph' (T), reportedly a grapefruit/sweet orange hybrid, is similar to seedy white grapefruit with earlier maturity and lower bitterness. 'Jackson' (J) is a low-seeded budsport of 'Triumph'. Tree health and productivity of T, J, and standard cultivars 'Marsh' (M) and 'Flame' (F) planted in a replicated field trial were assessed for 3 years, in a site with endemic HLB and CC. In each year, overall tree health (a visual integration of canopy thickness, lack of dieback, and freedom from foliage disease) of T/J was significantly greater than M/F. Severity of CC was significantly less on T/J than on M/F, while foliar HLB symptoms in the fall were similar among cultivars. Titers of Liberibacter asiaticus were assessed by PCR in Jan. 2010; there were no significant differences among cultivars in random leaf samples or most-symptomatic diagnostic samples in the 2010 analyses. M/F developed very thin canopies while T/J had normal canopy density. T/J had extensive blotchy mottle characteristic of HLB on leaves year-round while M/F trees appeared to drop severely HLB-symptomatic leaves in the winter. Cumulative numbers of fruit/tree were greater for T/J (255/220) than for M/F (29/66). Tree height of T/J was slightly greater than in M/F. Canopy volume was greater in T/J than M/F in some years, but trunk cross-sectional area (TCSA) was not different, and there were no cultivar differences in TCSA increase over the study period. Cumulative percent fruit drop was greater in M/F than T/J (F=50; M=53; T=15; J=14). Fruit quality assessments were made each cropping season. T/J fruit always met commercial maturity standards whereas M/F fruit usually did not due to low total soluble solids and low Brix/acid ratios. In 2011–2012 many M/F were small and/or misshapen while T/J fruit were of normal size and shape. These results suggest that T/J or other grapefruit-like cultivars may be viable alternatives to standard grapefruit cultivars in the presence of severe HLB and CC, with apparent tolerance to HLB in T/J. More importantly, it provides evidence that useful tolerance to HLB may exist within conventional scion genotypes.

The citrus diseases huanglongbing (HLB, associated with *Candidatus* Liberibacter asiaticus) and citrus canker (CC, caused by *Xanthomonas citri*) are greatly impacting the Florida citrus industry and HLB has now been found in California and Texas as well (CDFA, 2012). Trees of many citrus genotypes, such as the sweet orange (*Citrus sinensis*) and grapefruit (*Citrus paradisi*) that dominate the Florida industry, become less productive when affected by HLB, often exhibiting greatly thinned canopies and dieback. Characteristic leaf symptoms such as "blotchy mottle" are observed, with symptoms most readily apparent in fall and winter months (M. Irey, personal communication). Fruit size, appearance, and quality are also often adversely affected as the disease advances (Bové, 2006).

Citrus canker damages foliage and fruit of susceptible varieties, and grapefruit is among the most susceptible genotypes. In addition to reducing tree thriftiness by foliar damage, and causing preharvest drop of fruit with extensive CC lesions (Bock et al., 2010), the presence of CC within a grove may prevent fresh fruit sales to markets that are currently free of CC (Gottwald et al., 2009).

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The USDA/ARS citrus breeding program maintains collections of diverse germplasm and has many acres of unique hybrid seedlings which were made to advance citrus improvement. The USDA–ARS Ft. Pierce farm is heavily affected by HLB and CC and farm-wide control of these diseases is minimal to facilitate research on control measures and disease resistance, which permits observation of genotype responses in the presence of severe HLB and CC pressure.

The primary grapefruit cultivars of commerce, such as 'Flame', 'Marsh', 'Ray Ruby', 'Red Blush', 'Rio Red', and 'Star Ruby', are near-isogenic sports produced through mutations and selected for traits like low-seed-number or red color, in an iterative process building on cultivars previously selected for their beneficial mutations (Corazza-Nunes et al., 2002; Gmitter, 1995; Saunt, 2000). These cultivars ultimately derive from the original grapefruit, which likely was very similar to 'Duncan'. There are cultivars (e,g., 'Imperial', 'Royal', and 'Triumph') with similar fruit characteristics that are also known as grapefruit, but differ markedly in genotype from the primary grapefruit cultivars (Corazza-Nunes et al., 2002) and are likely hybrids of true grapefruit. The "oldest named grapefruit" according to Citrus Industry Vol. 1 (Hodgson, 1967) is 'Triumph', which is considered a likely hybrid between grapefruit and sweet orange. 'Triumph' fruit are quite similar to those of 'Duncan', but with somewhat smaller size and less early-season bitterness. 'Jackson' is reported to be a low-seeded

budsport of 'Triumph', which originated in South Africa (Hodgson, 1967). Prior to the development of HLB and CC epidemics in Florida, a trial of 'Triumph', 'Jackson', 'Marsh', and 'Flame' was established at the USDA Ft. Pierce farm to compare potential for early-season fresh fruit and juice production.

A number of hybrid seedlings and trees of existing cultivars at the USDA farm appear to demonstrate resistance or tolerance to HLB, at least to the strain(s) of Liberibacter present. In 2009, it appeared that 'Triumph' and 'Jackson' may be among the genotypes with resistance or tolerance to HLB. Data were collected on the existing planting over the next 3 years to test the hypothesis that 'Triumph' and 'Jackson' would perform significantly better than 'Marsh' and 'Flame' under the test conditions.

Materials and Methods

Experimental trees were 'Triumph', 'Jackson', 'Marsh', and 'Flame' planted on a range of common citrus rootstocks in 2003–2004 on the USDA/ARS Ft. Pierce farm in two-row bedded culture. The site was comprised of Nettles and Pineda soil types, which are loamy, siliceous, hyperthermic, arenic glossaqualfs and have excellent suitability for citrus production. Trees were ground-fertilized and microsprinkler-irrigated using standard commercial practices. Prior to and during the test period, pest-control was applied in a program appropriate for processing fruit prior to the advent of HLB and CC.

The planting was established with 12 or more trees of each scion on a range of standard rootstocks. For the data reported here, each block was defined based on consistent rootstock and time of planting without consideration of current tree status, resulting in 11 trees of each scion (four on Carrizo, three on Cleopatra, two on Sun Chu Sha, and two on Swingle) distributed randomly across the planting. As blind blocking did not exclude trees that had died prior to data collection, two 'Flame' and one tree each of 'Jackson' and 'Triumph' were found to be dead at the start of our data collection and were handled as missing data, and no further mortality occurred in the ensuing 3 years.

Tree data collected. The following variables were measured annually during the winter: trunk circumference 2.5 cm (1 inch) above the graft union, tree height, and canopy width along and across the row. These data were used to calculate canopy volume (Albrigo et al., 1975) and trunk cross-sectional area using Excel (Microsoft Corp., Redmond, WA). Trees were scored for overall health (a visual integration of canopy thickness, lack of dieback, and freedom from foliage disease), CC symptoms (severity and incidence as foliar lesions), and HLB symptoms (as severity and incidence of foliar blotchy mottle) each winter as follows: 1= fully healthy to 5= severely unhealthy. Each fall, total fruit on each tree and fruit dropped from each tree were counted with total fruit per tree and percentage drop calculated. Analysis of variance on all of these data was conducted using SAS (Cary, NC) with mean separations using Duncan's multiple range test and contrast analyses on 'Marsh'+'Flame' vs. 'Triumph'+'Jackson' run on each parameter.

On 23 Sept. 2009, leaf samples were collected from each cultivar in five of the randomized complete-blocks. Three-leaf samples were randomly selected from four quadrants of each of the selected trees (terminal leaves from next to last flush) and assayed as described below. Additionally, a sample of leaves showing severe blotchy mottle HLB symptoms was collected from each tree and assayed. Nucleic acid was extracted from citrus leaf laminar discs (3-mm diameter, ~11 mg) using REDExtract-N-Amp (Sigma, St. Louis, MO) according to manufacturer's instructions. CLas 16S rDNA in citrus leaf nucleic acid extracts was amplified using qPCR following standard protocol (Li et al., 2006) to generate Ct values. Each sample was assayed in triplicate. Positive, negative and no template controls were included in each q-PCR run. A Ct value of 40 was assigned when there was no detectable amplicon replication. No standard data transformation resulted in Ct-derived data satisfying assumptions for analysis of variance, so Ct means were compared using the nonparametric Kruskal-Wallis analysis (SAS, Cary, N.C.).

Fruit quality data collected. In 2009–2010, fruit were harvested on three dates (6 Nov. 2009, 20 Jan. 2010, and 19 May 2010) to assess differences in fruit quality throughout the potential market season. On each of the first two dates, 10 fruit were randomly selected from one tree of each cultivar on each of Swingle, Carrizo, and Cleo. Trees selected could not be consistent within a specific designated randomized complete block due to irregular cropping and the need for 30 fruit (10 fruit per sample date) on sampled trees. On the third sampling date there were sufficient fruit for only one sample of 'Marsh' and one sample of 'Flame' with the full three samples analyzed of 'Triumph' and 'Jackson'. Due to poor quality of 'Marsh' and 'Flame' fruit in 2009–2010, the decision was made to collect data on a single sample date for the next two seasons. On 15 Dec. 2010, ten fruit were again collected from one tree of each cultivar on Swingle, one on Carrizo, and one on Cleo. On 13 Feb. 2012, balanced samples could not be collected so that each cultivar was represented on the same rootstocks, and four trees of each cultivar with adequate fruit were randomly sampled.

For each replicate on each date, 10 fruit were analyzed for fruit weight, diameter, seed number, and peel color. Canker symptoms were assessed on each piece of fruit by numerical rating (0=none, 1=slight, 2=moderate, 3=severe) in the first two growing seasons and in 2012 was scored as to the percentage of fruit surface displaying canker lesions and analyzed as percentage of fruit with lesions detected. Fruit color measurements were taken equatorially at three evenly spaced locations using a Minolta Chromameter (model CR-300, Minolta Camera Corp., Ramsey, NJ). In 2009–2011 peel thickness and height were also measured on each fruit. Juice was combined from the 10-fruit sample to assess total soluble solids (TSS), titratable acidity (TA; percent anhydrous citric acid), and juice content. Juice was extracted in 2009–2011 using a hand-reamer and in 2012 by cutting the fruit in half and placing face down on a Brown model 2700 test juice extractor (Brown's Machinery, Winter Haven, FL). TSS was measured using a digital, temperature-compensated refractometer (PAL-1, ATAGO U.S.A., Inc., Bellevue, WA) and TA was measured by titrating juice samples to pH 8.3 with NaOH using a Mettler titrator (model DL12, Highstown, NJ).

Results and Discussion

Tree data. This project was initiated because trees of 'Triumph' and 'Jackson' appeared to be substantially healthier than those of 'Marsh' and 'Flame' in the experimental planting. The data collected supported this observation as trees of 'Triumph' and 'Jackson' were consistently rated as healthier than those of 'Marsh' and 'Flame' (Table 1) in each of the 3 years of this study, with a P-value of <0.0001 in contrast analyses comparing the two groups in each year. The main factors contributing to a "healthier" rating were thicker canopies on 'Triumph' and 'Jackson' and less dieback (Fig. 1). All of the trees displayed severe HLB blotchy

Table 1. Data collected on a replicated trial of 'Flame' (F), 'Marsh' (M), 'Jackson' (J) and 'Triumph' (T) at a site in Ft. Pierce, FL where haunglongbing (HLB) and citrus canker (CC) are severe and widespread. Tree health (a visual integration of canopy thickness, lack of dieback, and freedom from foliage disease), CC symptoms (severity and incidence as foliar lesions), and HLB symptoms (as severity and incidence of foliar blotchy mottle) were all rated on a 5-point scale such that 1 is healthy and 5 is severely affected.

Tree data collected winter of 2009–2010 season

Cultivar	Health rating	HLB rating	Canker rating	Tree ht (m)	Tree canopy vol (m^3)	Fruit per tree	Fruit drop (%)
Flame (F)	3.3 b	3.7 a	3.6 b	2.2 c	5.9 b	62.3 bc	62 b
Marsh (M)	3.5 b	3.5 a	3.6 b	2.3 bc	6.0 b	42.2 c	69 b
Jackson (J)	2.1 a	3.6 a	1.6 a	2.8 a	8.9 a	126.1 a	21 a
Triumph (T)	2.6 a	3.7 a	2.0 a	2.6 ab	8.7 a	100.2 ab	24 a
Contrast							
F&M vs. J&T	<0.0001	0.7053	<0.0001	0.0011	0.0141	0.0028	<0.0001

Tree data collected winter of 2010–2011 season

Cultivar	Health rating	HLB rating	Canker rating	Tree ht (m)	Tree canopy vol (m^3)	Fruit per tree	Fruit drop (%)
Flame (F)	4.1 b	3.8 a	2.9 b	2.0 b	5.7 b	22.7 b	5 a
Marsh (M)	4.6 b	3.7 a	3.1 b	2.2 b	5.9 b	8.8 b	21 b
Jackson (J)	3.2 a	3.1 a	1.5 a	2.8 a	9.6 a	82.4 a	4 a
Triumph (T)	2.8 a	4.2 a	1.7 a	2.7 a	9.8 a	94.5 a	5 a
Contrast							
F&M vs. J&T	<0.0001	0.6663	0.0005	<0.0001	0.0026	<0.0001	0.0013

Tree data collected winter of 2011–2012 season

Cultivar	Health rating	Tree ht (m)	Tree canopy vol (m^3)	Fruit per tree	Fruit drop (%)
Flame (F)	4.2 b	2.2 a	7.3 a	35.1 ab	29 a
Marsh (M)	4.4 b	2.2 a	6.1 a	15.5 b	31 a
Jackson (J)	2.5 a	2.4 a	8.7 a	11.4 b	25 a
Triumph (T)	2.4 a	2.4 a	8.7 a	60.4 a	27 a
Contrast					
F&M vs. J&T	<0.0001	0.0396	0.1260	0.4389	0.5754

Cumulative data over three seasons 2009–2012

Cultivar	Fruit per tree	Fruit drop (%)	TCSA increase (cm^2)
Flame (F)	129.4 bc	50% b	16.9 a
Marsh (M)	66.5 c	53% b	12.5 a
Jackson (J)	219.9 ab	14% a	9.6 a
Triumph (T)	255.1 a	15% a	13.9 a
Contrast			
F&M vs. J&T	0.0002	<0.0001	0.2609

[z]Means followed by the same letter within any column are not different at the $P = 0.05$ as determined by Duncan's New Multiple Range Test.
[y]Contrast analyses comparing the two true grapefruit, 'Marsh' and 'Flame' vs. the two grapefruit hybrids 'Jackson' and 'Triumph', in SAS Proc GLM..

mottle symptoms in the winter when they were assessed, with no significant difference between cultivars (Table 1). In the spring and early summer months, when HLB symptoms are normally less pronounced, leaves with strong blotchy mottle symptoms were present in 'Triumph' and 'Jackson' but not 'Marsh' and 'Flame' (data not shown). Most of the blotchy mottle leaves were in the canopy interior where leaves had completely abscised in 'Marsh' and 'Flame', suggesting that blotchy mottle leaves may continue to contribute to photosynthesis in 'Triumph' and 'Jackson', and thus are maintained on the trees. Canker ratings were markedly higher in 'Marsh' and 'Flame' than in 'Triumph' and 'Jackson', but canker lesions were evident on all trees and differences in severity of canker infection did not appear to explain the differences observed in overall tree performance.

Tree height and canopy volume were generally greater in the trees of 'Triumph' and 'Jackson' vs. 'Marsh' and 'Flame', but no differences in trunk cross-sectional area (TCSA) were observed and growth throughout the three year study period was modest with no difference between cultivars (Table 1). No differences due to rootstock were observed from statistical analyses on any data category except that trees on Swingle had lower TCSA than trees on other rootstocks (data not shown).

Numbers of fruit per tree were assessed in November or December in each year with fallen fruit included in the overall fruit/tree assessment and calculation of percentage of fruit drop. In all three years, 'Triumph' was in the most heavily cropping group as indicated by mean-separation, as was 'Jackson' in the first two years of this study (Table 1). In the third year of the study, cropping remained unacceptably low in 'Marsh' and 'Flame' and markedly declined in 'Triumph' and 'Jackson' compared to

previous years. Such data might be consistent with 'Triumph' and 'Jackson' displaying a cropping reduction related to HLB which was only slightly delayed compared to 'Marsh' and 'Flame'. However, counts of green fruit on 18 June 2012 indicated means of 13 fruit/tree in 'Flame', 6 fruit/tree in 'Marsh', 181 fruit/tree in 'Jackson', and 138 fruit/tree in 'Triumph'. It is possible that cropping in 2011–2012 was compromised by 19 h of freezing temperatures between 7 Dec. and 15 Dec. 2010, with the low seeded 'Jackson' seemingly more adversely affected than the seedy 'Triumph'.

Greater fruit drop is a common observation in HLB-affected citrus (Bové, 2006). In this study (Table 1), when assessed on 4 Nov. 2009 drop was markedly greater in 'Marsh' and 'Flame' (62% and 69%) than in 'Triumph' and 'Jackson' (24% and 21%), while on 2 Nov. 2010 'Marsh' had 21% drop vs. 4–5% in the other cultivars. In 6 Dec. 2011, all cultivars averaged about 30% drop. Due in part to heavier cropping of 'Marsh' and 'Flame' in 2009 when high drop was observed, cumulative drop over the 3 years of study was markedly higher in 'Marsh' and 'Flame' (50% and 53%) vs. 'Triumph' and 'Jackson' (15% and 14%).

Ct values for *Candidatus* Liberibacter asiaticus were assessed by PCR on leaves from random quadrant samples and most symptomatic samples. No significant differences were observed between cultivars for mean quadrant or mean diagnostic Ct values by Kruskal Wallis nonparametric analysis (Table 2).

Fruit quality data. In the 2009–2010 cropping year, fruit were harvested at three dates spanning the projected harvest season for grapefruit, to assess potential that 'Triumph' and 'Jackson' might provide usefully earlier maturity than 'Marsh' and 'Flame'. A single harvest date was used for fruit assessments in the ensuing two years. Fruit harvested 10 Nov. 2009 met standards for fresh fruit and juice in all but 'Marsh': only 'Triumph' and 'Jackson' met quality standards for the harvests (Florida Statutes, 2011) on 20 Jan. 2010, 19 May 2010, 12 Dec. 2010, and 13 Feb. 2012 (Table 3). It is noteworthy that the very sick trees of 'Marsh' and 'Flame', with greatly compromised canopies, produced fruit with extremely poor internal quality. Using contrast analysis to combine cultivar types, total soluble solids (TSS) and the ratio of TSS to titratable acidity (TA) was found to be significantly greater in 'Triumph' and 'Jackson' than in 'Flame' or 'Marsh' on all sampling dates. In every case except the 19 May 2010 harvest, TA was greater in 'Marsh' and/or 'Flame' compared to 'Triumph' and 'Jackson'.

'Jackson' was always similar in seed count to 'Marsh' and 'Flame' while 'Triumph' was extremely seedy. The seedy 'Triumph' had larger fruit than the other cultivars (except 'Marsh' on 19 May 2010) and sometimes had a lower ratio of juice to fruit wt., perhaps reflecting the large number of seeds. The fruit size of 'Jackson' was generally comparable to 'Marsh' and 'Flame' except that 'Marsh' and 'Flame' fruit size became more variable and smaller in the last harvest (2012) as tree health continued to decline (Fig. 2). Fruit diameter data are not shown since mean separations for this variable were identical to those for fruit weight data. The general fruit shape as reflected by ratio of height to width was similar across all cultivars (data not shown). Fruit rind thickness differences varied between cultivars in an inconsistent manner on the two dates assessed but were generally comparable between varieties (Table 3). All cultivars tested had smooth rind surfaces typical of grapefruit.

Fruit canker ratings in contrast analyses between 'Marsh' and 'Flame' vs. 'Triumph' and 'Jackson' always showed less canker on 'Triumph' and 'Jackson'. This is consistent with lower foliar symptoms for canker in these cultivars. Interestingly, H.A. Lee reported in 1921 that 'Triumph' grapefruit is in a class of cultivars where successful canker management is possible, while in "American grapefruit," canker control is "not economically practicable" (Lee, 1921). Presumably "American grapefruit" refers to cultivars such as 'Duncan' and 'Marsh'.

Colorimetry data showed some significant differences but mainly reflected the reddish blush on 'Flame' compared to the other three cultivars (data not shown).

Conclusions

'Triumph' and 'Jackson' trees maintained greater tree health than 'Marsh' and 'Flame', as well as providing greater cropping and better fruit quality under the test conditions of severe exposure to HLB and citrus canker. Since all trees were infected with *Candidatus* Liberibacter asiaticus (CLas), it appears that 'Triumph' and 'Jackson' may have a useful level of tolerance to HLB, with substantially greater canopy health than sweet orange and grapefruit trees grown nearby with the same management and similar tree age (Fig. 1). It is possible that this merely represents a modest delay in decline, but results are none-the-less promising and merit further assessment. Sustainable production in the presence of HLB may be further enhanced by combining tolerant/resistant material, with selection of rootstocks providing reduced HLB susceptibility (Grosser, personal communication), and use of enhanced nutrient management (Spann et al., 2010). 'Triumph' and 'Jackson' may also provide a level of canker resistance that could facilitate production of lesion-free fruit when grown with more extensive canker-control measures.

While the appearance of 'Triumph' (and 'Jackson') fruit is very similar to standard grapefruit, the flavor is not identical, in different sources reported as "lacking in bitterness and exceptionally good" (Hodgson, 1967), "a unique, smoother flavor without

Table 2. Ct values for *Candidatus* Liberibacter asiaticus assessed by pcr on leaves from a replicated trial of 'Flame', 'Marsh', 'Jackson', and 'Triumph' at a site in Ft. Pierce, FL where haunglongbing (HLB) and citrus canker are severe and widespread. Random quadrant samples and most blotchy-mottle symptomatic diagnostic samples were collected on 5 trees of each cultivar on 23 Sept 2009. Samples which showed no amplification were assigned a Ct value of 40. No significant differences were observed between cultivars for mean quadrant or mean diagnostic Ct values by Kruskal Wallis nonparametric analysis.

	Leaves sampled 23 Sept 2009					
Cultivar	SW quadrant	SE quadrant	NE quadrant	NW quadrant	Mean quadrant	Mean diagnostic
Flame	33.6	34.2	38.2	33.0	34.8	33.6
Marsh	37.1	32.4	31.9	33.5	33.7	32.8
Jackson	34.7	34.6	33.0	35.2	34.4	31.9
Triumph	37.6	36.5	36.1	38.6	37.2	34.2

Table 3. Data collected on fruit from a replicated trial of 'Flame' (F), 'Marsh' (M), 'Jackson' (J), and 'Triumph' (T) at a site where haunglongbing (HLB) and citrus canker are severe and widespread. All measurements are from 10 fruit samples, with juice data collected on a composite sample from the 10 fruit. Data were from three or four trees of each cultivar on each sampling date, except that on 19 May 2010 there were sufficient fruit for only one sample of 'Marsh' and one sample of 'Flame' with the full three samples analyzed of 'Triumph' and 'Jackson'.

Fruit data from harvest 10 Nov 2009

Cultivar	Fruit wt (g)	Fruit canker rating	Fruit rind thickness (mm)	Total soluble solids	Titratable acidity	TSS/TA ratio	Wt of juice/fruit (g)	Ratio juice to fruit wt
Flame (F)	255 b[z]	1.2 ab	5.5 c	8.0 b	1.1 b	7.6 b	98 ab	0.38 ab
Marsh (M)	223 b	1.6 a	7.3 a	7.6 b	1.4 a	5.5 c	91 ab	0.41 a
Jackson (J)	235 b	0.6 b	6.1 bc	9.3 a	1.0 b	9.4 a	85 b	0.36 b
Triumph (T)	348 a	0.8 b	6.8 ab	8.9 a	1.0 b	9.3 a	109 a	0.31 c
Contrast[y]								
F&M vs. J&T	0.0075	0.0134	0.8107	0.0019	0.0034	0.0003	0.6854	0.0017

Fruit data from harvest 20 Jan 2010

Cultivar	Fruit wt (g)	Fruit canker rating	Total soluble solids	Titratable acidity	TSS/TA ratio	Wt of juice/fruit (g)	Ratio juice to fruit wt
Flame (F)	227 bc	1.4 a	7.7 b	1.1 b	7.1 b	95 a	0.42 a
Marsh (M)	167 c	1.5 a	6.8 b	1.5 a	4.6 c	50 b	0.32 a
Jackson (J)	269 b	0.6 b	10.3 a	1.2 b	8.9 a	100 a	0.37 a
Triumph (T)	373 a	0.4 b	9.7 a	1.1 b	8.9 a	118 a	0.32 a
Contrast							
F&M vs. J&T	0.0007	0.0016	<0.0001	0.0346	0.0003	0.0198	0.4825

Fruit data from harvest 19 May 2010

Cultivar	Fruit wt (g)	Fruit canker rating	Total soluble solids	Titratable acidity	TSS/TA ratio	Wt of juice/fruit (g)	Ratio juice to fruit wt
Flame (F)	246 c	0.7 b	7.8 b	1.2 a	6.4 b	79 b	0.46 a
Marsh (M)	381 a	1.4 a	6.7 b	1.1 a	6.3 b	79 b	0.41 a
Jackson (J)	338 b	0.7 b	9.8 ab	1.0 a	10.2 a	126 a	0.37 ab
Triumph (T)	395 a	0.6 b	11.6 a	1.0 a	11.3 a	113 ab	0.29 b
Contrast							
F&M vs. J&T	0.0064	0.0668	0.0395	0.2801	0.0012	0.0204	0.0228

Fruit data from harvest 12 Dec. 2010

Cultivar	Fruit wt (g)	Fruit canker rating	Fruit rind thickness (mm)	Total soluble solids	Titratable acidity	TSS/TA ratio	Wt of juice/fruit (g)	Ratio juice to fruit wt
Flame (F)	188 b	1.5 a	4.2 b	7.2 b	1.4 b	5.3 b	70.4 b	0.37 b
Marsh (M)	158 b	1.2 a	5.7 a	6.4 b	1.4 b	4.5 c	54.5 b	0.34 b
Jackson (J)	199 b	0.3 b	3.9 b	8.7 a	1.1 a	7.9 a	84.3 b	0.42 a
Triumph (T)	312 a	0.2 b	4.7 b	9.0 a	1.2 a	7.6 a	122.3 a	0.39 ab
Contrast								
F&M vs. J&T	0.0650	<0.0001	0.0341	0.0007	0.0009	<0.0001	0.0027	0.0106

Fruit data from harvest 13 Feb. 2012

Cultivar	Fruit wt (g)	Fruit with canker lesions	Total soluble solids	Titratable acidity	TSS/TA ratio	Wt of juice/fruit (g)	Ratio juice to fruit wt	Seed per fruit
Flame (F)	275 c	22% ab	8.0 ab	1.13 b	7.0 b	123 b	0.45 a	2.6 a
Marsh (M)	209 c	30% b	7.5 b	1.32 c	5.7 c	94 c	0.43 a	2.0 a
Jackson (J)	363 b	14% ab	9.2 a	0.86 a	10.6 a	149 b	0.42 a	3.0 a
Triumph (T)	514 a	3% a	8.8 ab	0.91 a	9.6 a	220 a	0.44 a	40.5 b
Contrast								
F&M vs. J&T	0.0001	0.0278	0.0112	0.0001	0.0001	0.0001	0.759	0.0001

[z]Means followed by the same letter within any column are not different at $P = 0.05$ as determined by Duncan's New Multiple Range Test.
[y]Contrast analyses comparing the two true grapefruit, 'Marsh' and 'Flame', vs. the two grapefruit hybrids 'Jackson' and 'Triumph', in SAS Proc GLM.

the infamous bitterness traditionally associated with grapefruit" (International Supermarket News, 2012), and "flavor sweeter and more orangey than grapefruit; light citrange aftertaste, not pleasant" (Kahn and Siebert, 2009). 'Jackson' fruit from South Africa are now being marketed in the UK (International Supermarket News, 2012), suggesting some commercial potential.

Red-pigmented grapefruit now reflect a large proportion of market demand, and 'Triumph' and 'Jackson' are both yellow in color. Budwood of 'Jackson' has been irradiated in our program and resulting trees will be monitored for pigmented sports. We

Fig 1. Typical trees of (**left**) 'Flame', (**center**) 'Valencia', and (**right**) 'Triumph' of similar age in the USDA Ft. Pierce farm photographed on 30 May 2012. Health and appearance of 'Marsh' trees were very similar to those of 'Flame', and trees of 'Jackson' were similar to those of 'Triumph'.

Fig. 2. Cropping in the experimental planting photographed on 30 Jan 2012. On the **left** is 'Marsh' with tree and fruit appearance very similar to 'Flame': this tree had more fruit per tree than most but was selected to show distribution of fruit appearance. On the **right** is 'Triumph' with tree and fruit appearance very similar to 'Jackson'. Note variable size, color, and misshapen fruit in 'Marsh' while 'Triumph' fruit are large and relatively uniform.

are also growing 'Jackson', and a number of other promising cultivars and selection, in the greenhouse with and without CLas infection to more accurately assess the level of HLB tolerance.

Florida-grown 'Jackson' and possibly 'Triumph' may have fresh-fruit and/or juice market potential from groves where HLB and canker represent significant threats. Of more far-reaching significance is that some conventional scion cultivars/hybrids are displaying apparent tolerance to HLB, at least to the strains currently present at the USDA Ft. Pierce farm. It is interesting that 'Triumph' and 'Jackson' which appear to be hybrids of sweet orange and grapefruit (SSR marker assessment of 'Triumph' and 'Jackson' using polymorphic markers for sweet orange and grapefruit are consistent with this earlier report based on phenotype. Stover and McCollum, unpublished data), have far greater tolerance than either parent genotype (Fig. 1). A number of hybrids in the USDA citrus-breeding program appear to have useful tolerance to HLB and some of these are very similar in fruit phenotype to established citrus cultivars including sweet oranges.

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