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Variability in Detachment Force and Other Properties of Fruit Within Orange Tree Canopies

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Abstract

Three studies were conducted to identify patterns of fruit detachment force (FDF) and other fruit properties of 'Hamlin,' 'Pineapple' and 'Valencia' oranges [*Citrus sinensis* (L.) Osbeck] located in different sectors of the tree canopy. FDF of fruit of all 3 cultivars was lower in the interior of the canopy than on the exterior. The FDF of 'Hamlin' oranges was reduced in the lower portion of the canopy. The FDF of all 3 cultivars was positively correlated with fruit weight, and negatively correlated with juice content, Soluble solid concentration (SSC) of the juice and SSC/acid ratio were significantly higher in the upper and exterior sections of the trees than in the lower and interior sections. These results are useful for the development of efficient mechanical harvesting operations including the application of abscission chemicals.

Introduction

Harvest labor is a major expense to the citrus grower, accounting for approximately 40% of the total production cost in Florida (6). Thus, the future cost and availability of fruit pickers is of great concern. For these reasons, commercial mechanized harvesters are being developed for oranges intended for juice processing in Florida (1). Ninety-five percent of Florida's orange crop is processed. Most of the acreage of the major processing cultivars ('Hamlin,' 'Pineapple' and 'Valencia') can be adapted to mechanical harvesting methods. Unfortunately, estimates of recovery of mechanically harvested oranges range from 60 to 95% depending on the type of harvester (12). The efficiency of fruit removal from the tree is related to fruit maturity (juice SSC, titratable acidity (TA) and SSC/TA ratio) and the force necessary to detach that fruit at the abscission zone on the peduncle (2). Sites and Reitz (7, 8, 9) and Fallahi et al. (3, 4), however, found that orange fruit maturity varies within the tree canopy. Variability in fruit maturity and FDF could influence the rate of recovery of mechanically harvested oranges and the loosening response to abscission chemicals.

The objective of this study was to determine the variability of FDF and fruit quality attributes within the canopy of processing orange cultivars, and to determine if fruit located in specific sectors of the tree are more prone to resist removal by mechanical shaking.

Materials and Methods

Fruit of 'Hamlin,' 'Pineapple' and 'Valencia' orange cultivars were sampled in 3 separate studies conducted in 1997 to determine variability in FDF, fruit weight, juice content, juice weight, fruit diameter, soluble solid concentration (SSC), titratable acidity (TA) and SSC/TA ratio in different sectors of the tree canopy. Three trees (replicates) were used in each study.

In the first study, 7-year-old 'Hamlin' seedling trees, approximately 4.8 m tall and spaced at 6.5 ⑨ 2.3 m, were sampled on January 7-9 in Lake Alfred, FL, from 8 canopy sectors consisting of exterior/interior, upper/lower half of the tree and east/west compass directions. Trees were grown in a north-south hedge-row. Therefore, only east and west sectors were sampled. In a second study, 22-year-old 'Pineapple' orange trees on 'Cleopatra' mandarin (*Citrus reticulata* Blanco) rootstocks in Dundee, FL, were sampled on

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January 23-25. These trees were approximately 5.4 m tall, and spaced at 4.5 ⑨ 4.5 m. In the third study, 9-year-old 'Valencia' orange trees, 3.6 m tall on rough lemon (*C. limon* Burm. f.) rootstocks, spaced at 4.5 ⑨ 7.5 m, were sampled on March 18 and 19. Sample locations consisted of 16 sectors, namely combinations of exterior/interior, upper/lower and east, west, north and south directions.

In each study, exterior fruit consisted of exposed fruit within the outer 0.3 m of the canopy. Interior fruit were unexposed fruit located more than 0.3 m inside the canopy. Twenty mature fruit from each sector were removed from the tree by clipping the peduncle approximately 5 cm from the point of attachment to the fruit and brought to the laboratory. FDF was measured in kg force using a Wagner Instruments (Greenwich, CT) 'Force Five' digital force gauge by pulling the fruit by hand parallel to the fruit axis until it separated from the peduncle. The diameter of each fruit as well as the peduncle of 'Valencia' oranges was measured with calipers. The fruit was weighed and the juice extracted using a bench-top Sunkist reamer (Sunkist Growers, Los Angeles, CA). The juice was weighed and analyzed for SSC and TA. SSC was measured using a hand refractometer (Fisher Scientific, PA). The TA was determined by titrating a 25 ml aliquot of juice against a 0.3125 N sodium hydroxide solution and calculating the percent anhydrous citric acid by weight (11).

The data from each study were statistically analyzed as a 3-factorial experiment using SAS statistical software (SAS Institute, Cary, NC). Means were separated by Duncan's multiple range test at P = 0.05 after analysis of variance indicated significant F values. Linear correlation coefficients were calculated for FDF and other fruit characteristics. No significant interactions between canopy positions were detected; thus, pooled data for upper-lower and interior-exterior positions, and compass direction are presented.

Results and Discussion

Fruit quality attributes: There were no significant differences in fruit weight of 'Hamlin' oranges within the tree, although juice content was higher in the interior of the canopy (Table 1). Juice content was also higher in the lower and east portions of the canopy. Fruit diameter was higher in the upper and west portions of the canopy. Fruit SSC was significantly higher in the exterior and upper parts of the canopy. Juice TA was lowest in the upper canopy. The SSC/TA ratio was significantly lower in the interior and lower sections of the tree.

In general, the 'Pineapple' cultivar had similar fruit quality attributes as 'Hamlin' orange (Table 2). TA content was highest

Table 1. Study 1. Effect of canopy position on the detachment force (FDF) and maturity of 'Hamlin' fruit harvested in Lake Alfred, FL, on January 7-9, 1997, from 7-year-old trees.

Position in canopy	FDF (kg)	Fruit weight (g)	Juice weight (g)	Juice content (%)	Fruit diameter (mm)	Soluble solids (%)	Titratable acid (%)	SSC/TA Ratio
Exterior	9.94 a^z	194.4 a	89.9 b	46.4 b	72.3 a	10.7 a	0.81 a	13.4 a
Interior	8.50 b	198.9 a	94.9 a	47.8 a	72.4 a	10.2 b	0.82 a	12.7 b
Upper	10.07 a	198.3 a	91.8 a	46.4 b	72.8 a	10.6 a	0.80 b	13.5 a
Lower	8.36 b	195.1 a	93.0 a	47.8 a	71.9 b	10.2 b	0.83 a	12.6 b
East	9.05 a	194.8 a	92.1 a	47.4 a	71.8 b	10.4 a	0.80 a	13.1 a
West	9.39 a	198.6 a	92.7 a	46.7 b	72.9 a	10.5 a	0.82 a	13.0 a

^{z}Mean separation between two canopy sectors by Duncan's multiple range test, P = 0.05.

Table 2. Study 2. Effect of canopy position on the detachment force (FDF) and maturity of 'Pineapple' fruit harvested in Dundee, FL, on January 23-25, 1997, from 22-year-old trees.

Position in canopy	FDF (kg)	Fruit weight (g)	Juice weight (g)	Juice content (%)	Fruit diameter (mm)	Soluble solids (%)	Titratable acid (%)	SSC/TA Ratio
Exterior	10.03 a[z]	216.7 b	97.8 b	45.3 b	64.9 b	10.7 a	0.76 b	14.6 a
Interior	9.47 b	243.1 a	118.9 a	49.1 a	67.2 a	9.8 b	0.89 a	11.2 b
Upper	9.65 a	224.0 b	105.0 b	47.0 a	65.7 a	10.4 a	0.78 b	13.9 a
Lower	9.86 a	235.8 a	111.6 a	47.4 a	66.3 a	10.0 b	0.86 a	12.0 b
East	9.35 b	226.6 a	107.7 a	47.2 a	65.9 a	10.2 a	0.83 a	12.9 a
West	10.16 a	233.2 a	109.9 a	47.2 a	66.2 a	10.3 a	0.82 a	12.9 a

[z]Mean separation between two canopy sectors by Duncan's multiple range test, P = 0.05.

in the interior and lower portions of the tree as were the SSC/TA ratios.

As with 'Hamlin' and 'Pineapple' oranges, 'Valencia' fruit had larger fruit and higher juice weight in the tree interior and higher SSC and SSC/TA ratio in the tree exterior. No differences in fruit maturity were found between the compass orientations with the 3 cultivars studied..

In extensive sampling studies, Sites and Reitz (7, 8, 9) identified variability in 'Valencia' fruit quality from 19 separate sectors of the tree. They found the highest SSC and TA in exterior fruit from the southeast and southwest sectors with only little difference in TA and the highest SSC/TA ratios in the northeast sectors. Interior fruit had lower juice contents than exterior fruit suggesting that fruit quality factors are related to intensity and duration of light. Fallahi et al. (4), confirmed higher fruit weight, juice content and SSC from external canopy positions in 4 citrus cultivars. Fallahi and Moon (3) showed that leaves from the canopy exterior had higher $C0_2$ assimilation rates than interior leaves. Syvertsen and Albrigo (10) reported that southern top canopy positions yielded more fruit and more soluble solids than other canopy positions. Higher SSC and lower TA were found in the canopy exterior. Upper canopy positions had

Table 3. Study 3. Effect of canopy position on the detachment force (FDF) and maturity of 'Valencia' fruit harvested in Lake Alfred, FL, on March 19, 1997, from 9-year-old trees.

Position in canopy	FDF (kg)	Fruit weight (g)	Juice weight (g)	Juice content (%)	Fruit diameter (mm)	Soluble solids (%)	Titratable acid (%)	SSC/TA Ratio
Exterior	11.03 a[z]	197.6 b	108.3 b	4.2 a	56.0 a	12.6 a	1.08 a	12.1 a
Interior	10.32 b	226.0 a	126.0 a	4.0 b	56.5 a	11.6 b	1.11 a	10.7 b
Upper	10.81 a	211.8 a	116.6 a	4.2 a	55.8 a	12.3 a	1.13 a	11.3 a
Lower	10.54 a	211.9 a	117.7 a	4.0 b	56.6 a	11.9 a	1.05 a	11.5 a
North	10.75 ab	211.2 a	115.4 a	4.4 a	56.4 a	12.0 a	1.13 a	11.1 a
East	10.54 ab	209.2 a	116.1 a	3.9 c	56.2 a	12.1 a	1.10 a	11.3 a
South	10.93 a	212.6 a	117.6 a	3.9 c	56.6 a	12.0 a	1.03 a	11.8 a
West	10.49 b	214.2 a	119.5 a	4.1 b	55.7 a	12.2 a	1.11 a	11.3 a

[z]Mean separation between two or four canopy sectors by Duncan's multiple range test, P = 0.05.

Table 4. Correlation coefficients of fruit detachment force with fruit characteristics of 'Valencia,' 'Hamlin' and 'Pineapple' orange.

Characteristic	Valencia[z]	Hamlin[y]	Pineapple[y]
Fruit weight	0.637	0.230	0.408
Fruit diameter	0.528	0.218	−0.033
Stem diameter	0.599	not determined	
Juice content	−0.745	−0.275	−0.369
Soluble solid content	−0.392	0.219	−0.019
Titratable acid	0.717	−0.072	−0.315
SSC/TA ratio	−0.659	0.172	0.274

[z]Significant at P = .95 if > 0.280, at P = 0.99 if > 0.360.
[y]Significant at P = .95 if > 0.130, at P = 0.99 if > 0.180

higher TA and SSC/TA ratios than the lower positions. Our data confirmed that exterior fruit exposed to the sun had higher contents of soluble solids. Exposed fruit also had a higher FDF and the two characteristics were negatively correlated in 'Valencia' oranges (Table 4).

Fruit Detachment Force (FDF): FDF of mature 'Hamlin,' 'Pineapple' and 'Valencia' oranges located in the interior of the canopy was significantly lower than for fruit in exterior positions. We measured thinner stem diameters on interior Valencia oranges (Table 3) that were correlated with lower FDF. Differences in FDF between fruit in the upper and lower sectors of the canopy were measured only in 'Hamlin' trees (Tables 1, 2, 3).

Fruit from 'Hamlin' and 'Valencia' trees grown in hedge-rows had no significant differences in FDF in the east/west portions of the canopies (Tables 1 and 3). Fruit from 'Pineapple' were looser on the east side of the tree than on the west (Table 2). Fruit from 'Valencia' trees were significantly looser on the west side than on the south side of the tree (Table 3).

FDF was significantly correlated with fruit size as expressed by weight and diameter (Table 4). 'Valencia' fruit found in the upper and exterior canopy sections exposed to the sun developed stronger stems and, thus, were attached more firmly, despite the higher sugar content and SSC/TA ratios which were correlated with lower FDF.

Since mechanical removal of orange fruit from the tree by shakers is influenced by fruit inertia, fruit weight and FDF are principal properties affecting the fruit recovery (2). Removal by harvesting mechanisms that rely on direct fruit contact (e.g. canopy shaker), on the other hand, is influenced more by fruit size and location in the tree than strength of fruit attachment.

Although variability of FDF was high within the various sectors of the canopy of the 3 cultivars sampled, fruit located in the upper exterior of the canopy consistently had the highest FDF and therefore would resist removal by trunk shaker most.

For optimal removal of fruit by mechanical trunk shakers, uniform FDF throughout the tree is preferable. The objective of using abscission chemicals as part of a mechanical harvesting system is to reduce FDF and loosen orange fruit uniformly for maximum fruit recovery. Our results indicate the importance of adequate coverage of abscission material sprays, especially directed at fruit in the upper areas of the tree to insure uniform loosening. The point-source air-blast sprayers commonly used in the citrus industry direct a majority of the spray solution into the lower tree half. Responses to abscission agents appear to be most effective with high volume application that assure good coverage throughout the canopy, but may cause over-dosing and preharvest fruit drop in some portions of the canopy while only insufficiently loosening fruit at the top (5). Research is needed to determine optimum equipment and spray volume to achieve uniform fruit loosening.

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