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Daily Fluctuation in Fruit Detachment Force of 'Valencia' Orange Is Related to Time of Day, Temperature, Relative Humidity, Fruit Weight, and Juice Percentage

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Throughout the course of our research addressing topics related to abscission, we noted differences in fruit detachment force (FDF) that were dependent upon the time of day measurements were taken. We tested the hypothesis that diurnal fluctuations in FDF exist in mature citrus fruit (*Citrus sinensis* cv. Valencia). FDF was measured at 8 AM, 11 AM, 2 PM, and 5 PM for several consecutive days each month in Jan., Apr., and May 2007. Fruit weight and juice content were determined for samples harvested at 8 AM and 2 PM. Hourly averages for temperature and relative humidity were recorded by the nearby University of Florida's Florida Automated Weather Network (FAWN). Daily fluctuation in FDF changed 4% to 23% within a period from 8 AM to 5 PM. Fluctuations in FDF were correlated with time of day, temperature, relative humidity, juice percentage, and fruit weight. Efficacy of abscission agents was increased when applying at 1 PM when daily FDF was low. Abscission agent-associated fruit and leaf drop responded in a similar manner to application time. These results demonstrate diurnal fluctuations in FDF exist in mature citrus fruit, and that these daily changes can be used to manage fruit response to abscission agents.

Predictable and consistent reduction in fruit detachment force (FDF) after application of abscission agents to citrus canopies is critical to achieve uniform fruit removal with mechanical harvesters. Previous work demonstrated that abscission agent-induced reduction in FDF varied with citrus cultivar (Kender et al., 1999; Pozo et al., 2004) and time of season (Pozo and Burns, 2006; Yuan et al., 2001). Moreover, natural (Kender and Hartmond, 1999) and abscission agent-induced (Burns et al., 2006) FDF varied depending upon fruit position within the canopy. To our knowledge, no work has been done to define variation in natural or abscission agent-induced FDF during the day. Diurnal FDF fluctuations could provide an explanation for variation in FDF leading to variable fruit removal between field experiments due to disparate daily application times. We hypothesized that diurnal fluctuations in FDF exist in mature citrus fruit. If diurnal FDF patterns exist, it may be possible to manage abscission agent efficacy and uniformity of removal by applying at key times of the day.

Materials and Methods

Plant material and FDF measurements. Seventeen-year-old 'Valencia' (*Citrus sinensis* L. Osbeck) orange trees, grafted on Swingle rootstock located at the Citrus Research and Education Center, Lake Alfred, FL, were used for this study. Trees were irrigated according to standard irrigation practices and considered well-watered. Experiments were initiated in January (early season fruit), early April (mid season fruit), and late May (late season fruit) 2007. For FDF measurements, five 6-tree-plot replicates were randomly selected from across the grove. Each replicate consisted of 10 fruit per plot; five per row side. FDF measurements were taken at 8 AM, 11 AM, 2 PM, and 5 PM during cycles of up to 5 d in Jan., Apr., and May 2007, using a digital force gauge ('Force Five', Wagner Instruments, Greenwich, CT) as described (Pozo et al., 2004). Following FDF measurements, fruit sampled at 8 AM and 2 PM were weighed, cut in half, and juice removed using a hand-held juice extractor (Sunkist 319G-UL Model 8-R, Sunkist Growers, Inc., Sherman Oaks, CA). Juice was weighed to determine juice percentage.

Abscission agents and application procedures. Abscission agents used in this work were ethephon [2-ethyl-2-phosphonic acid ('Ethrel®, 21.7% ethephon w/v), Aventis Crop Science, Research Triangle Park, NJ] and CMNP [5-chloro-3-methyl-4-nitro-1*H*-pyrazole (ASI-100 17EC, 17.2% CMNP w/w), AgroSource Inc., Westfield, N.J.]. Spray solutions contained the organosilicate adjuvant Kinetic® (Setre Chemical Co., Memphis, TN) at 0.1% (v/v). Abscission treatments were applied to three entire trees to runoff using a motorized 20-L capacity back sprayer (SP Systems, Forza 25SP, Santa Monica, CA). CMNP [0, 125, and 250 mg·L^{-1} (ppm)] and ethephon (0, 300, and 600 ppm) were applied at 9 AM and 1 PM on 19 and 25 May 2007, respectively. Adjuvant only controls applied at 9 AM and 1 PM were used in all experiments. Rainfall did not occur between application and FDF measurements in all trials reported. FDF readings were taken 4 d after application at 2 PM as described above. Mature fruit and leaf drop were measured by counting organs immediately prior to each application and at the end of the experiment. Results are expressed as a percentage of the total mature fruit or leaves at the beginning of each experiment. Replicates for CMNP-associated fruit drop were pooled, so for this abscission agent, only the means for each time and concentration were calculated. Leaf drop was low in all CMNP treatments and not counted.

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Hourly temperature and relative humidity. Hourly summarized weather data for temperature and relative humidity (RH) were recorded by Florida Automated Weather Network (FAWN), Institute of Food and Agricultural Sciences, University of Florida.

Statistics. Percentage data were transformed to stabilize variance using arcsin transformation in MS-Excel functions (Microsoft, Redmond, WA). Data were analyzed within each spray date as a one-way factorial with spray treatment as the independent variable. Analysis of variance, regression analysis, and Duncan's multiple range tests were performed using the Sigma Plot Software, Version 10.0, and SAS statistical package (SAS Inst. Inc., Cary, NC).

Results

Daily fluctuation of natural FDF. FDF in early, mid, and late season fruit showed that FDF was highest at 8 AM and lowest at 2 or 5 PM in a given day (Fig. 1). The magnitude of FDF fluctuations were greatest in mid season fruit, whereas late season fruit showed the least differential between high and low FDF values during the day. In all cases, the fluctuation cycles were repeated in 24-h intervals. Depending on fruit maturity, diurnal changes in FDF ranged from 4% to 23% of the highest FDF value in a 24-h cycle.

Temperature, RH, time of day, fruit weight, or juice content and FDF. Temperature and RH hourly data were obtained for all sampling dates; however, only the 2–7 Apr. 2007 data corresponding to mid season fruit are shown. FDF declined as temperature rose and vice versa (Fig. 2), indicating negative correlation between temperature and FDF. In contrast, RH, fruit weight and juice percentage changes paralleled FDF changes, suggesting positive correlation between each variable and FDF. These patterns were consistent for early, mid, and late season cycles, including trees under water stress (data not shown). Regression analysis indicated significant correlations between the dependent variable FDF and independent variables time of day, temperature, RH, juice percentage, and fruit weight (Table 1).

Application time and efficacy of CMNP or ethephon. CMNP or ethephon applications performed at 1 PM when natural FDF was low were more efficacious than those applied at 9 AM the same day when FDF was high, regardless of the concentration used (Fig. 3). Fruit drop was numerically greater when the lowest concentration of each abscission agent was applied at 1 PM rather than 9 AM. Ethephon-associated leaf drop followed the same pattern. At the highest abscission agent concentration, larger differences in fruit drop were measured. Leaf and fruit drop percentage were significantly greater when 600 ppm ethephon was applied at 1 PM.

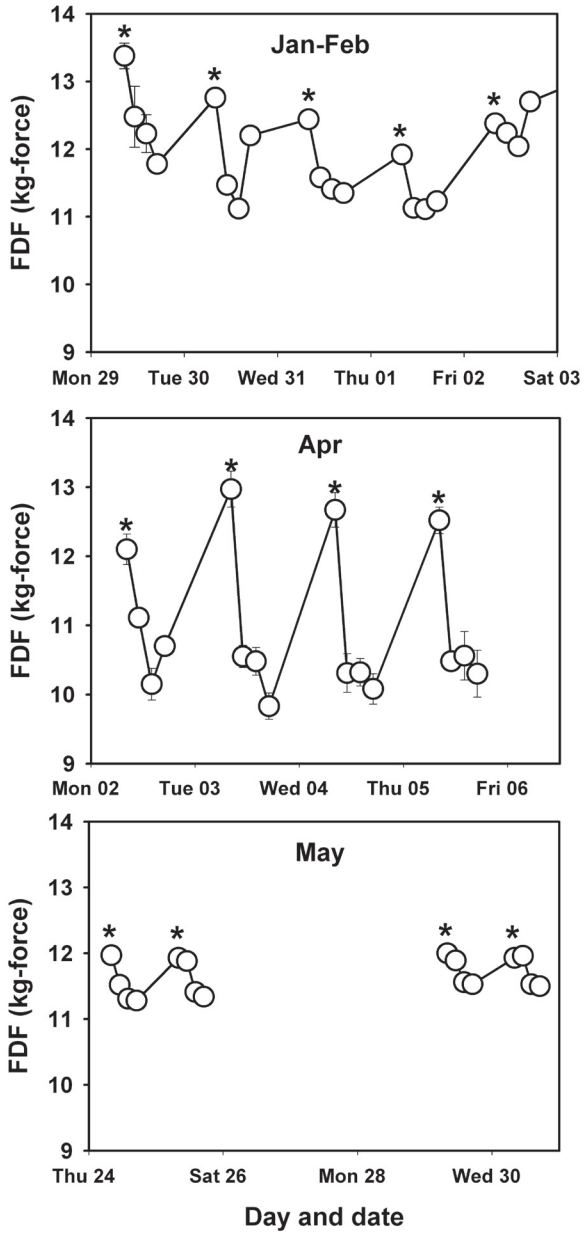

Fig. 1. Daily fluctuation in FDF in early season (29 Jan.–3 Feb., **top panel**), mid season (2–6 Apr., **middle panel**), and late season (24–25, 29–30 May, **bottom panel**) 'Valencia' orange fruit. Data presented are means ± SE. Absence of SE bars indicates markers larger than SE. Asterisks indicate an 8 AM measurement. The data points successively to the right of the 8 am measurement were taken at 11 AM, 2 PM, and 5 PM.

Discussion

A major research challenge in working with acceleration of abscission is uniform FDF reduction in treated and control fruit. We show in this work that significant fluctuation in daily FDF occurs in mature fruit. Measurements taken at 8 AM can differ from those taken at 2 PM by over 20%, suggesting that sampling at disparate times of the day contributes to variation in FDF. Not only are these fluctuations in FDF significantly correlated with time of day, but also with temperature, RH, juice percentage and fruit weight. Reduced fruit water potential occurs in the afternoon and is higher at dusk and dawn (Syvertsen and Albrigo 1980) and this may play a role in diurnal change in FDF. It is likely that many factors, including time of day, fruit water potential, and RH interact to alter diurnal FDF magnitude and pattern.

Lower abscission agent concentration was needed when application was performed when natural FDF was low. Furthermore, fruit drop could be altered by application of abscission agents at different times of the day. This has practical implications for fruit drop management when the citrus crop is to be mechanically harvested. Fruit drop can be minimized if abscission agent application is performed in the morning when natural FDF is high. Mechanical harvesters operating with a catch-frame would benefit, since there would be minimal fruit lost to the ground

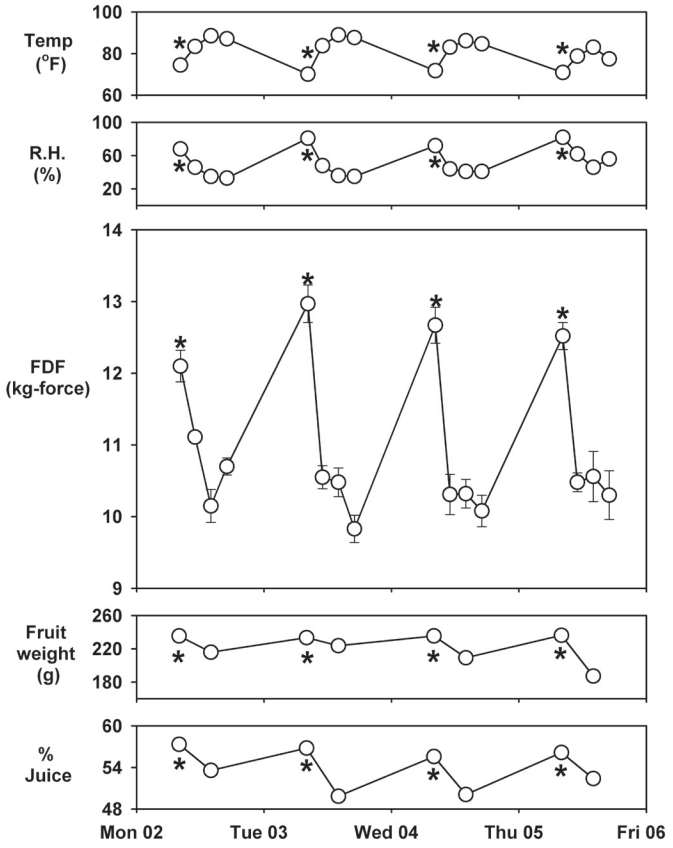

Fig. 2. Daily fluctuations in temperature, relative humidity (RH), FDF, fruit weight, and percent juice during a 5-consecutive-day cycle from 2–6 Apr. 2007 in 'Valencia' orange. Temperature and RH data are hourly averages downloaded from the Florida Automated Weather Service (FAWN) database. Means of FDF, fruit weight, and percent juice are plotted with standard error (SE). Absence of SE bars indicates SE smaller than mean markers. Asterisks indicate an 8 AM measurement. The data points successively to the right of the 8 AM measurement were taken at 11 AM, 2 PM, and 5 PM; for fruit weight and percent juice, the alternate measurement is 2 PM.

Table 1. Regression comparison, regression equation, regression coefficient (R^2), and *P* value for the dependent variable fruit detachment force (FDF) and independent variables time of day (t), temperature (T), relative humidity (RH), % juice (J), and fruit weight (FW). Data are from the 2–6 Apr. 2007 test.

Comparison	Regression equation	R^2	*P*
FDF vs. t	$y = 21.22 - 1.49x + 0.05x^2$	0.73	<0.0001
FDF vs. T	$y = 88.88 - 1.83x + 0.0106x^2$	0.71	<0.0001
FDF vs. RH	$y = 11.72 - 0.08x + 0.0012x^2$	0.68	<0.0001
FDF vs. J	$y = 78.56 - 2.85x - 0.03x^2$	0.59	<0.0001
FDF vs. FW	$y = 13.43 - 0.06x + 0.0002x^2$	0.37	0.0002

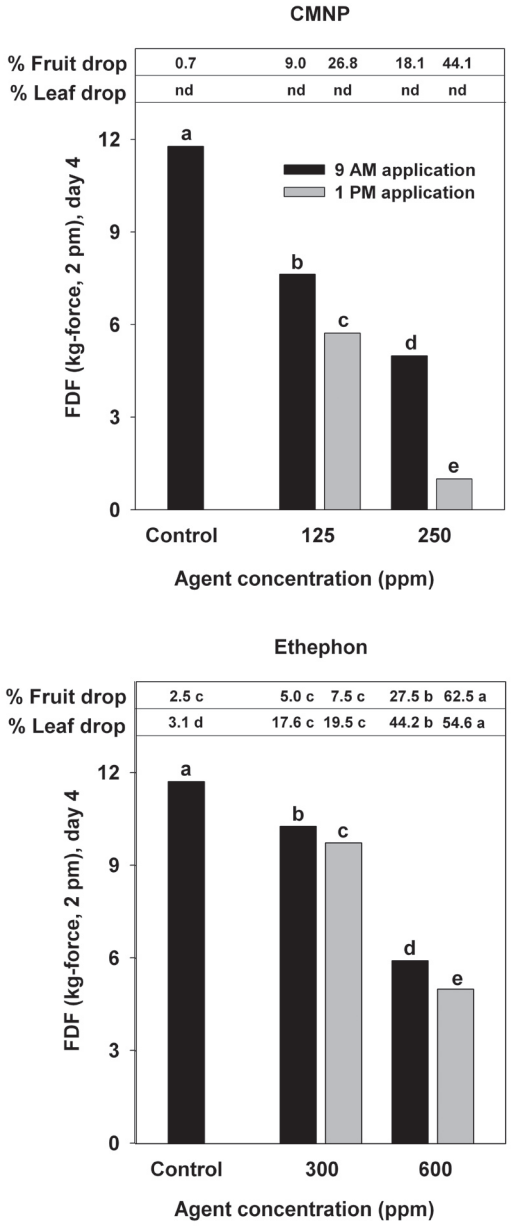

Fig. 3. Reduction in FDF and fruit drop in 'Valencia' orange fruit 4 d after treatment with 0, 125, and 250 ppm CMNP (**upper panel**) or 0, 300, and 600 ppm ethephon (**lower panel**). Treatments within an abscission agent with the same letter are not significantly different, $P \leq 0.05$. Fruit and leaf drop (%) are shown at the top of each graph. For ethephon, means followed by the same letter are not significantly different, $P \leq 0.05$. For CMNP, percent fruit drop for all replications was pooled so only the means are presented. Leaf drop was not determined (nd) but visually deemed to be low without treatment differences.

before harvesting is accomplished. On the other hand, mechanical harvesters operating without a catch-frame would not be negatively impacted by preharvest fruit drop, so the time of day applications are performed would not be critical. In either scenario, as long as a 50% reduction in FDF was achieved after abscission agent application, fruit removal using mechanical harvesters is maximized (Burns et al., 2005). Furthermore, it may be possible to use less abscission agent if application is done when natural FDF is low.

The basis of the diurnal fluctuation, although influenced by factors examined in this work, is unknown. Our preliminary work suggests that fruit appear to be more sensitive to ethylene-accelerated abscission in the afternoon when natural FDF is low (Malladi, John-Karuppiah, and Burns, unpublished results). The interaction of light and water status is likely to play a prominent role in daily FDF changes in citrus. Future work will focus on defining additional diurnal physiological changes occurring in mature fruit tissues and utilizing the information to effectively manage the abscission response.

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