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Characteristics and oleocellosis sensitivity of citrus fruits

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ABSTRACT

The effects of variety, growth phase, and water loss on development of oleocellosis, and relationships between chromatism and Vis/NIR spectra were studied in 'EarlyGold' sweet orange (*Citrus sinensis* Osbeck), 'Fukumoto' navel (*Citrus sinensis* Osbeck), and 'Cara Cara' navel (*Citrus sinensis* Osbeck) oranges. The varieties showed significant differences in the rate (RO) and degree (DO) of oleocellosis development. The sensitivity of varieties (from most to least sensitive) was 'EarlyGold' > 'Fukumoto' > 'Cara Cara.' Growth phase and water loss had a significant influence on fruit sensitivity to oleocellosis. The order of sensitivity to oleocellosis was dependent on harvest time (i.e., at normal period > at delayed period > at uncolored period), and RO and DO decreased significantly with water loss. The RO and DO models for fruit water loss were established as $y = 0.75 - 3.94x - 271.33x^2$ ($R^2 = 0.77$) and $y = 1.70 - 7.29x - 1025.83x^2$ ($R^2 = 0.583$). The sensitivity of 'EarlyGold' to oleocellosis was significantly correlated with d*L* and d*C* of fruit chromatism. At the same time, there were significant differences at 480–575 nm, 650–720 nm, and 925–965 nm between varieties with low and high sensitivity to oleocellosis, and 'EarlyGolds' with a low RO and DO had a higher reflectance than those with a high RO and DO.

1. Introduction

Oleocellosis is a physiological rind disorder of citrus fruit caused by the release of phytotoxic oil from glands within the rind (Knight et al., 2001) following mechanical damage (Fawcett, 1916). Oil from ruptured glands can spread over the rind and induce symptoms. Rind damage on colored fruit initially shows as a slight reduction in gloss, followed by the collapse and discoloration of cells between oil glands, leaving obvious visible pitting (Shomer and Erner, 1989). Oleocellosis results in heavy losses to growers and shippers of navel orange and other citrus varieties picked early in the season when the rinds are green. This disorder is more serious in fruits harvested in wet than in dry conditions. The disorder causes a considerable reduction in external fruit quality and fresh fruit exports. Up to 80% of fruit can be affected in more sensitive orchards (Almela et al., 2000).

There have been a number of reports on causes of oleocellosis in different varieties of citrus. Nutritional imbalance (Chapman, 1958; Grierson, 1965), climate change from rain to wind (Zaragoza and Alonso, 1975), cold winds (Klotz et al., 1966), sudden changes in relative humidity (Agustí and Zaragoza, 2000), and development of differential water stress across the rind (Zacarias et al., 2001) are involved in the rind breakdown of the 'Navelate' orange. Consequently, daily variations in relative humidity and evapotranspiration in relation to the natural occurrence of rind staining have been studied. Moreover, postharvest induction of oleocellosis in mature fruit showed that it takes place irrespective of harvest time but increases with fruit maturity (Alférez and Zacarías, 2001). However, the mechanism of oleocellosis development is still not clearly understood.

Non-destructive optical methods based on visible/near-infrared spectroscopy (VNIR) have been evaluated for non-destructive estimation of soluble solids content, water content, dry matter content, acidity, firmness, stiffness factor and others physiological properties of a number of fruit products, including citrus (Steuer et al., 2001) and mandarin (McGlone et al., 2003). Jim Hill (SARDI) had developed inexpensive instruments to measure the rind turgor pressure of citrus and relevant environmental conditions. These instruments were sold as an "Oleocellosis Prediction Kit" (Jim,

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2004). However, fruits are needed to be destructive. It would not be able to fulfil its ambition to sort manually or automatically on the basis of citrus sensitivity to oleocellsis.

The objective of this study was to evaluate the relationship between rind characteristics (including chromatism and visible/near-infrared reflectance (Vis/NIR) spectra) and oleocellosis development after mechanical damage among 'EarlyGold' sweet and 'Cara Cara' and 'Fukumoto' navel oranges to provide a basis for non-destructive optical methods. The effect of water loss and growth phase on the rate (RO) and degree (DO) of oleocellosis development was also examined to reduce oleocellosis in subsequent storage stage.

2. Materials and methods

2.1. Plant material

Oranges of three varieties ('EarlyGold' sweet [*Citrus sinensis* Osbeck], 'Fukumoto' navel [*Citrus sinensis* Osbeck], and 'Cara Cara' navel [*Citrus sinensis* Osbeck]) were picked thrice from an experimental orchard of 20-year-old trees grafted onto citrange Carrizo [*Citrus sinensis* (L.) Osb. × *Poncitrus trifoliata* (L.) Raf.] in the Citrus Research Institute, Southwest University, Chongqing, China, on 10 November 2008 (uncolored fruit), 15 December 2008 (normal harvest) and 20 January 2009 (delayed harvest). The study was conducted in 2008/2009 season, and 50 fruits were collected from 10 plants of each variety and used for analyses.

2.2. Chromatism and Vis–NIR spectrometry

Twenty 'EarlyGold,' 'Cara Cara,' and 'Fukumoto' fruits were randomly selected and damaged by pricking the skins. Fruit chromatism each treatment was examined using a Color Reader colorimeter (Konica Minolta CR-10) for estimation of '*L*,' '*a*' and '*b*' values; color values as Hue angle was calculated according to Mcguire (1992) and Voss (1992).

The experimental arrangement for testing citrus fruit included a Vis–NIR spectrometer (ASD FieldSpec® HandHeld (HH) (325–1075 nm with a 1.6 nm spectral sampling interval and 1 nm resolution), Analytical Spectral Devices, Inc., USA) with an external fiber-optic cable with high intensity contact probe, a Si detector for 325–1075 nm (VNIR), and a instrument controller to communicate with spectrometer using an Ethernet interface. Each fruit was placed on its side with the transverse equator located on top of a small circular plastic grommet (30 mm o.d.) that provided a simple means for holding the fruit in a light-tight manner. The fruit exterior to the grommet was illuminated from below by a broad band tungsten halogen lamp (model: A350610, 12 V/30 W) to provide light source, and the angle and distance between the incident light source and the detector fiber was 25° and 10 cm, respectively. A spectral on white panel (6.5 mm thick) was used as the reference standard for eliminating the characteristics of the light source. Each spectrum was accumulated over 2.10 s from six contiguous acquisitions at a 350 ms integration time. Vis–NIR spectra were collected and transformed by Indico software v4.0 (Analytical Spectral Devices, Inc., USA). For each citrus fruit, 4 spectra were recorded at different marked locations which were also prepared for subsequent mechanical damaged treatments.

2.3. Oleocellosis induction and symptom assessment

Selected fruits were damaged by pricking with a needle to induce oleocellosis immediately after measurement of chromatism and Vis/NIR spectra. Each fruit was stabbed through 16 oil glands at various positions, and then placed in storeroom at 20 °C and 50% relative humidity (RH). The average oleocellosis diameter of each treatment was assessed 1, 2, 3, 5, 7, and 20 days after induction. The total number of oleocellosis wounds with diameters >0.25 cm and <0.25 cm were recorded as x_1 and x_2, respectively. The ratio of oleocellosis (RO) and degree of oleocellosis (DO) of each fruit were calculated as follows:

$$\mathrm{RO} = \frac{x_1 + x_2}{16}$$

$$\mathrm{DO} = x_1^* 0.5 + x_2^* 0.25.$$

Note: The correlation coefficient (R^2) between DO and the total oleocellosis area of each fruit achieved to 0.92 (n = 20). So the DO can present the degree of oleocellosis of per fruit.

2.4. Water loss treatment

The initial weight of selected 15 fruits were recorded as x_1, and the weight of these selected fruits after 6 days at 20 °C and 50% relative humity (RH) storeroom were recorded as x_2. The ratio of water loss of each fruit (RWL) was calculated as follows: RWL = $(x_1 - x_2)/x_1$. Then these selected fruits were damaged by pricking with a needle to induce oleocellosis, and the RO and DO was measured 20 days after induction.

2.5. Statistical analysis

Data are expressed as mean ± SD of three independent experiments. All statistical analyses were performed using SPSS 13.0 (SPSS Inc., Chicago, IL, USA). One-way analysis of variance was used to compare the means. After analysis using Levene's test, means with equal variance were tested using least-squares determination, whereas means with unequal variance were analyzed using Dunnett's T3 test. Differences at $P < 0.05$ were considered significant. All fruit reflectance measurements were transformed to absorbance (first derivative) values using Viewspec pro 4.07 (Analytical Spectra Devices, Inc., Boulder, CO, USA).

3. Results

3.1. Effect of variety on oleocellosis development

The time course of oleocellosis diameter, RO, and DO of 'EarlyGold,' 'Fukumoto,' and 'Cara Cara' are shown in Fig. 1. The average oleocellosis diameter of all three varieties increased significantly up to 3 days, then slightly from day 3 to day 7 (Fig. 1D). However, the RO of 'EarlyGold' was slightly higher than that of 'Fukumoto,' and that of 'Fukumoto' was significantly higher than that of 'Cara Cara.' The DO of 'EarlyGold' was significantly higher than that of 'Fukumoto,' and that of 'Fukumoto' was significantly higher than that of 'Cara Cara' (Fig. 1A–C and E). This confirms that oleocellosis of 'EarlyGold,' 'Fukumoto,' and 'Cara Cara' developed within 3–5 days, and the different varieties have different sensitivities to oleocellosis harvest on 15 December 2008.

3.2. Effect of growth phase on oleocellosis symptoms

The effect of growth phase on RO and DO of 'EarlyGold' is shown in Fig. 2. The RO and DO at normal harvest date were significantly higher than at delayed harvest and for uncolored fruits, and the RO and DO of uncolored oranges were significantly lower than those of the normal and delayed harvest fruits. The results indicate that the growth phase of 'EarlyGold' has a significant influence on sensitivity to oleocellosis, and delayed harvesting can decrease the sensitivity of 'EarlyGold.'