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Nondestructive Detection of Section Drying, an Internal Disorder in Tangerine

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Abstract. **Near infrared (NIR) absorption spectrometry and X-ray computed tomography (CT) were used to nondestructively determine the presence of section drying, an internal disorder in tangerines (*Citrus reticulata* Blanco, cv. Dancy). X-ray CT scan images clearly differentiated areas with section drying from healthy sections of the fruit. Delineation was due to differences in X-ray absorption resulting from lower tissue density and water content in vesicles having the disorder. Second derivative NIR optical density values at 768 and 960 nm correlated strongly with the presence or absence of section drying, indicating that NIR optical properties of vesicles with section drying differed from those without the disorder. These results suggest that, compared with X-ray–based techniques, NIR absorption spectroscopy could be a less expensive, safe, and rapid method for the nondestructive sensing of section drying in citrus fruit.**

A number of juice vesicle disorders in citrus occur during fruit maturation and/or storage, with the severity of the problem increasing progressively with later harvests. A range of terms has been coined for vesicle disorders, e.g., granulation (Bartholomew et al., 1941; El-Zeftawi, 1978; Knorr, 1973; Sinclair and Jolliffe, 1961); crystallization and ricing (Knorr, 1973); vesicle collapse (Hwang et al., 1990); section drying (Burns, 1990; Burns and Achor, 1989); and core dryness and dry juice sac (Hwang et al., 1988). These can be segregated into two distinct classes of disorders, granulation and dehydration (Hwang et al., 1988). Granulation begins with hardening of the affected vesicles followed by gradual collapse of the inner cells resulting in an empty crystalline-like cavity. In contrast, dehydration begins with a slight shrinkage followed by complete collapse of the affected vesicles due to the loss of fluids. The general term section drying is used to refer to the condition where vesicles within a segment either appear dehydrated and/or collapsed or granulated (Burns and Achor, 1989).

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Very little is known about the exact cause of section drying, although factors such as crop load, location of the grove, fruit size, rootstock, cultivar, cultural practices, and climate appear to contribute to the condition. The initial severity and subsequent development of the disorder vary with season, grove, cultivar, harvest date, and length of storage. For example, Albrigo et al. (1980) reported severe section drying in 60% of grapefruit harvested in May and tested in July after 7 weeks of storage. Thus nondestructive detection and removal of defective fruit prior to sale would be highly advantageous. X-ray and near infrared spectroscopy (NIR) are two technologies that warrant testing for the nondestructive detection of section drying.

X-ray computed tomography (CT) is an important tool in diagnostic medicine. Computed tomography uses an array of detectors to measure non-absorbed X-rays passing through a thin trans-axial or cross-sectional segment of the sample. The CT image displays the internal structure of the segment, reconstructed by computer analysis of the transmitted X-ray data from multiple exposures. In conventional radiography, X-rays passing through a sample are recorded as different densities on film. The advantages of CT over conventional radiography include elimination of superimposed structures, imaging of minute differences in the density of anatomical structures and abnormalities, and superior image quality due to a reduction of scatter radiation (Chiu et al., 1995).

Both conventional radiography and CT techniques have been tested in nondestructive quality evaluation of certain fruits and vegetables. Thomas et al. (1993) used conventional X-ray imaging for detection of a spongy tissue disorder in mangoes. Likewise, preliminary tests using X-ray imaging were conducted to ascertain if internal citrus disorders (e.g., frost injury, granulation, and other internal desiccation problems) could be detected (Johnson, 1985). X-ray imaging can be used to detect hollow heart in potato (Rex and Mazza, 1989) and X-ray CT to determine fruit maturity in tomato (Brecht et al., 1991).

The major deficiencies of X-ray techniques are the high equipment and operating costs, safety considerations, and the time interval required for scanning (about 9 s per exposure). These limitations make alternative nondestructive techniques that are rapid, accurate, safe, and inexpensive worthy of consideration.

One such nondestructive technique, NIR transmittance spectroscopy, can detect internal disorders in a cross-section of fruits and vegetables (Birth, 1960; Birth and Olsen, 1964; Law, 1973; Timm et al., 1991). Light transmittance techniques for detecting internal disorders involve measuring either the intensity of radiation passing through the affected tissues or the loss of energy at specific wavelengths. The amount of radiation transmitted through the fruit is altered by the light-scattering properties of tissues, which in turn results in a change in the spectral composition of the transmitted radiation.

With section drying in citrus, internal physical and chemical properties such as color, density, texture, moisture content, elemental composition, sugar content, chemical composition of cell walls, and percent dry matter differ significantly between healthy and affected vesicles (Bartholomew et al., 1941; Hwang et al., 1990; Sinclair and Jolliffe, 1960). Therefore, differences in physical and/or chemical properties between normal and affected tissues may result in differences in optical properties that could be utilized to detect section drying. We report a series of preliminary tests directed toward determining the potential of differentiating impaired and healthy regions of tangerines by X-ray CT and NIR spectroscopy.

Materials and Methods

Late-harvested tangerines, a percentage of which, based upon random destructive sampling, displayed section drying in varying degrees were harvested at the Citrus Research and Education Center, Lake Alfred, Fla., and held at 10 °C until analyzed. X-ray CT scanning of fruit was carried out using a Toshiba TCT 20 AX X-ray CT scanner (Toshiba Corp., Tokyo, Japan). The scanner was operated at the 120 kV energy level and 390 mA-s photon intensity with a 10-mm collimation and a 9-s exposure. The X-ray target was tungsten. Four fruit were simultaneously scanned while held in a special wooden holder and oriented in such a manner that the scan plane was perpendicular to the stem–blossom axis. Three scans were taken through the bottom, middle, and top sections of the fruit along this axis. Fruit were marked to identify the orientation of scanned planes and the regions of section drying in the fruit, and for comparison with the scanned image and cut slices at the termination of the tests. The images were saved as tagged image files and retrieved on a PC using the Lotus Freelance Graphics software package. By inspecting the top, mid, and bottom scanned images, the regions with section drying were identified and marked on the surface of each fruit before taking NIR spectra.

Optical density (OD) spectra of affected and healthy areas of fruit were obtained with a fiber optic spectrometer (model SD 1000-TR; Ocean Optics, Dunedin, Fla.), which had a scanning range from 500 to 1000 nm. A light beam was generated by a tungsten halogen lamp operating at 12 V and 75 W of input power and passed through a 650 nm long pass cut-off filter. The beam was directed onto the surface of the fruit using an aluminum tube with an inner diameter of 10 mm. A fiber optic cable (400 µm) fitted with a collecting lens placed about 5 mm away from the input light tube collected radiation transmitted through the fruit and directed it to the detector. Reference spectra were taken with a 55-mm-diameter Teflon circular disk

An analog to digital converter card (CIO-DAS16/330; Computer Boards, Mansfield, Mass.) allowed the computer to receive and digitize the spectral data for processing via the SpectraScope spectral analysis software program (Ocean Optics, Dunedin, Fla.). The optical density data were converted to the Near Infrared Spectral Analysis Software (NSAS; NIRSystems, Silver Spring, Md.) format using a BASIC program. Mathematical transformation of spectral data and multiple linear regression analysis of data were performed using NSAS.

A total of 38 scans were taken from normal areas and another 26 scans from affected areas from 10 fruit previously subjected to X-ray CT scanning with identified regions of section drying. The spectrometer was set up at 40 kHz, 1 gain, 10 scans to average with short integration cycle, correction for dark on with data normalization off. The SpectraScope optical density data files were converted to NSAS format and section drying ratings (0 = normal, 1 = section drying visible) were merged with the spectral data. The second derivative spectral data were subjected to multiple regression analysis to identify two optimum wavelengths best correlated with section drying. The spectral data range used for analysis was limited to 750–1000 nm.

Results and Discussion

The presence of section drying in fruit was clearly discernible as dark areas in X-ray CT images (Fig. 1.) and compared well with the visual observations of cut slices. Absorption of X-rays is dependent on the water content and density of tissues. Studies with soils have shown that X-ray absorption is affected by bulk density and water content, with bulk density having roughly a five-fold greater effect on X-ray absorption than water content (Tollner, 1994). Since granulated or dehydrated tissues have less juice and thus are lower in bulk density, the X-ray absorption is proportionately low and the gray scale of the image is proportional to the severity of section drying (i.e., darker = more severe). One can also estimate the absorbance value for each pixel of the image and then calculate the degree of damage for each scanned slice and for the whole fruit so as to get a fairly representative estimation of overall fruit damage. However, since our objective was only to identify the areas of fruit having section drying for taking NIR spectra, we did not use X-ray CT data for image processing or quantification of the vesicle disorders.

Multiple regression analysis of NIR spectral data established that second derivative OD values at 768 and 960 nm correlated with section drying scores with a multiple correlation coefficient of 0.875. The relationship of the second derivative OD at these two wavelengths and the type of tissue from where the scans were taken (Fig. 2) show that areas with section drying and healthy regions of fruit have different optical characteristics. These preliminary results established that the NIR optical properties of healthy tissues vs. those having section drying are considerably different, and that these differences could be exploited as the basis for developing nondestructive NIR techniques for the detection of vesicle disorders for use in fruit sorting and grading lines.

Our experiments with NIR optical properties of oranges did not yield similar results, possibly due to the spectral noise created by the thick rind. However, the X-ray CT method was effective in identifying areas of section drying in orange. One critical requirement for developing a successful NIR technique is the use of a sufficiently high-intensity NIR beam

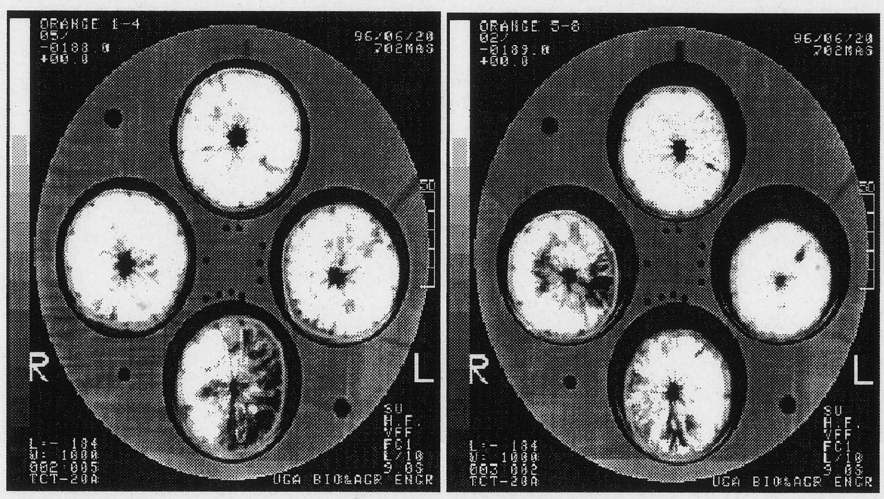

Fig. 1. X-ray CT images of tangerines with suspected section-drying disorder. The darker areas of the images are zones with section drying.

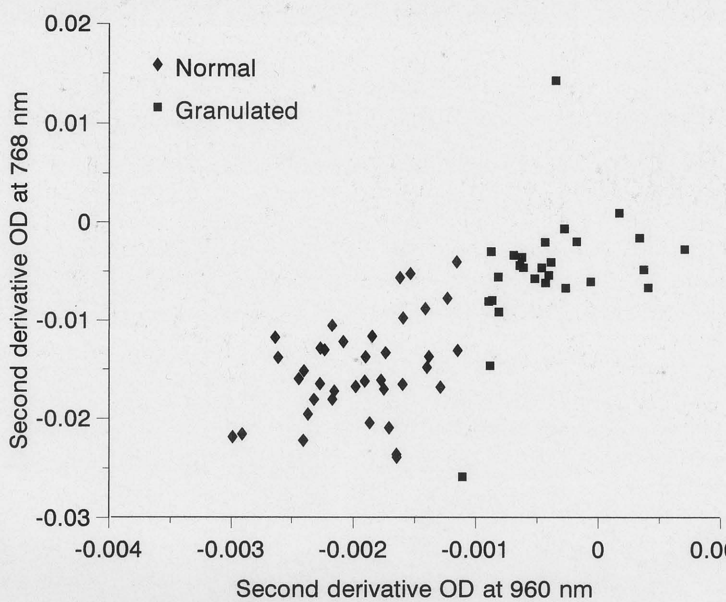

Fig. 2. Relationship between second derivative optical density values at 768 nm and 960 nm for normal and granulated sections of tangerines.

that can penetrate the fruit rind and interact with juice vesicles, and at the same time allow sufficient back scattering to be measured by the detector. It also should not damage the fruit with heat injury during scanning, since each fruit must be scanned several times at different locations to establish the presence of section drying before acceptance or rejection. Collimated beams coming from a high-intensity NIR source, or NIR lasers coupled with more sensitive spectrometers that can scan fruit quickly, may be useful in this regard and worth testing in future experiments, especially for fruits having rinds with varying thickness, such as orange and grapefruit.

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