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Research paper

Nondestructive assessment of watermelon flesh color by laser vibrometry

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A B S T R A C T

Flesh color of watermelon is often used as a major postharvest criterion by consumers to assess fruit quality. In this paper a non-destructive method was studied to determine watermelon (Crimson Sweet) internal color. Responses of samples to excitation vibrations were detected using laser Doppler vibrometry (LDV) technology. Phase shift between input and output vibrations were extracted overall frequency range. The frequencies of phase shifts which had the highest correlation with Hunter color values were selected. Regression models were developed to predict texture color using obtained results. The correlation coefficients of the calibration and cross validation models were 0.9 and 0.86 for a^* respectively. Those of L^* were 0.91 and 0.87. Meanwhile, cut watermelons were sensory evaluated by subjective scoring of color. Comparisons showed that correlations between objective measurements and consumer opinions were significant at the 0.01 level. This study demonstrated feasibility of laser vibrometery for predicting flesh color of watermelon.

1. Introduction

Watermelon is a popular fruit and it has different properties and applications. According to FAO statistics published in 2008, Iran has been ranked third among watermelon producing countries.

Nondestructive quality determination of watermelons has been a challenge for its customers since it has different structure from the other fruits. The subjective methods are usually based on appearance or sound caused by slap. Both are not reliable because these methods are prone to human errors. Researchers have studied different objective methods to evaluate watermelon quality: acoustic and dynamic technology (Yamamoto et al., 1980; Stone et al., 1996; Armstrong et al., 1997; Diezma-Iglesias et al., 2002; Jamal et al., 2005), electrical and magnetic technology (Kato, 1997; Nelson et al., 2007), X-ray and computed tomography (Tollner, 1993), and near infrared (NIR) spectroscopy (Ito et al., 2002; Flores et al., 2008; Sun and Huang, 2010).

The internal color of watermelon is one of the most important indicators of quality for customers especially when they want to buy cut fruits. Watermelon color is the first parameter considered by consumers and it is a significant factor in accepting or rejecting the product even before putting it inside the mouth.

Red color of watermelon is imparted by lycopene pigment (Xianquan et al., 2005). Lycopene is a red carotenoid with antioxidant properties and potential health benefits that may reduce the incidence of certain cancers. (Perkins-Veazie et al., 2001. Davis et al., 2003).

Research about finding flesh color of watermelon nondestructively is very rare in literature. Stone et al. (1996) developed a portable device by acoustic impulse impedance technique to determine the maturity of watermelons in the field. Tissue color was used as one of indicators of maturity. The best correlation coefficient between tissue color and acoustic parameters was 0.66.

In this paper laser Doppler vibrometry (LDV) technology is used to detect flesh color of watermelon. In recent years using LDV have

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been studied by researchers as a new nondestructive technique to test the quality of some fruits. Muramatsu did comparison between the use of accelerometer and LDV to measure the firmness of some varieties of apple, pear, kiwi and citrus. Their results of measurements carried out using the LDV expressed more accurate than the accelerometer results (Muramatsu et al., 1997). In addition, Muramatsu evaluated the texture and ripeness of some varieties of kiwi, peach and pears. They excited samples at different stages of ripeness, by the sine wave with frequencies from 5 to 2000 Hz and the vibration responses at top point of the fruit were measured by LDV. Then the phase shift between input and output signals was compared with the data obtained from the method of force-displacement. A significant relationship between these two methods obtained in 1200 and 1600 Hz excitation frequencies. The ability of the LDV technique for detection of internal defects of some citrus varieties was approved (Muramatsu et al., 1999). Muramatsu also used the method to conduct some tests and determine fruit texture changes during the ripeness. This technique was used for persimmon, apple and kiwi. In the range of 1200 to 1600 Hz, phase shift as a function of the ripeness significantly changed. They also found resonance frequency for all fruit under test was a function of the ripeness (Muramatsu et al., 2000). Terasaki applied LDV to measure kiwifruit ripeness. A stiffness coefficient was defined as $f_{n=2}^{2}.m^{2/3}$, where $f_{n=2}$ was the frequency of the second resonance peak and m was the fruit mass. A loss coefficient was defined as $(f_2 - f_1)/f_{n=2}$, where frequencies f_1 and f_2 were measured at 3 dB below the second resonance peak ($f_2 > f_1$). The results indicate that the two coefficients clearly distinguish between ripe and unripe kiwifruit. (Terasaki et al., 2001). The potential of measuring the vibration response with a laser vibrometer was explored in plums by Bengtsson. Phase shifts at selected frequencies were highly correlated to postharvest storage time, plum weight, plum length and plum width (Bengtsson et al., 2003). Murayama conducted research on ripeness by the LDV in which pears harvested at different times and in different periods of storage were tested. Results showed that correlation coefficients between firmness and elasticity index were significantly high (Murayama et al., 2006) Taniwaki also conducted a separate investigation to review the trend of change in elasticity index figures from the melon, persimmon and pear after harvest period. The second resonance frequency of sample was obtained using LDV. The samples were evaluated by panelists' senses considering features such as appearance, sweetness, firmness and etc. (each separately). High correlation between the elasticity index and the mentioned properties were observed (Taniwaki et al., 2008, 2009a,b,c).

The main objective of present study is establishing a relation among parameters measured by LDV and watermelon internal color using multiple linear regression models.

2. Materials and methods

In this study fifty two watermelons were selected for the experiments. The variety of watermelons was Crimson Sweet which is one of the varieties for export from the Iran. It is nearly round with bright green and medium dark stripes. The average and standard deviation of fruits mass were 4131 and 1791 g respectively.

The experimental setup has been presented in Figs. 1 and 2. A fruit sample was placed on a shaker (LSD V721, Low Force Shaker, B&K, Denmark), and excited with random wave signals (frequencies, 0–1000 Hz) generated and amplified using a computer and amplifier respectively. Experiment control such as determination random signal (white noise) and data recording was carried out by portable pulse 4/2 I/O module, dynax module. While the excitation signal was detected by accelerometer (DJB A/120/VT, DJB Instruments, Suffolk, UK) installed on vibrational plate, the response of the fruit was optically sensed using a Laser Doppler Vibrometer (Ometron VH1000-D, Ometron, Hertfordshire, UK).

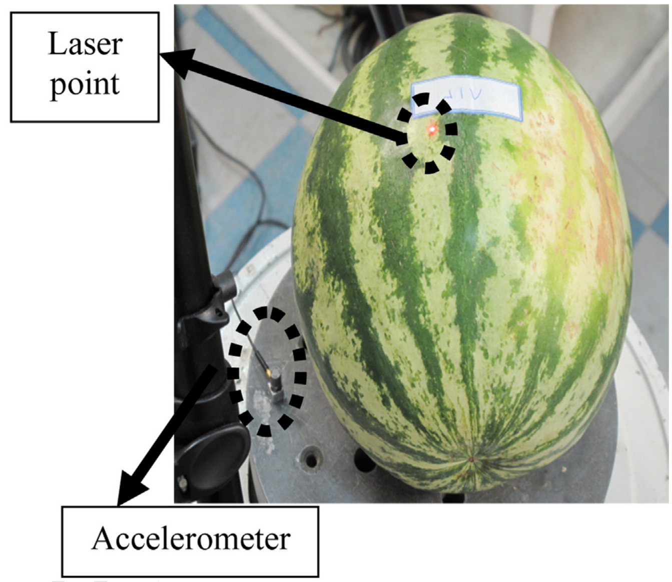

Fig. 1. Excitation signal was measured as input signal by accelerometer installed on shaker.

Briefly laser beam from the LDV is directed to the upper surface of sample and the vibrations are measured from the Doppler shift of the reflected beam frequency due to the motion of the surface. Considering the response signals, the excitation signals and using fast Fourier transformation (FFT), the phase shifts between the mentioned signals were extracted for entire frequency range. Vibrations transmission through the watermelons resulted in this phase shift.

The frequencies of the phase shifts which had the highest correlation with color indicators were chosen.

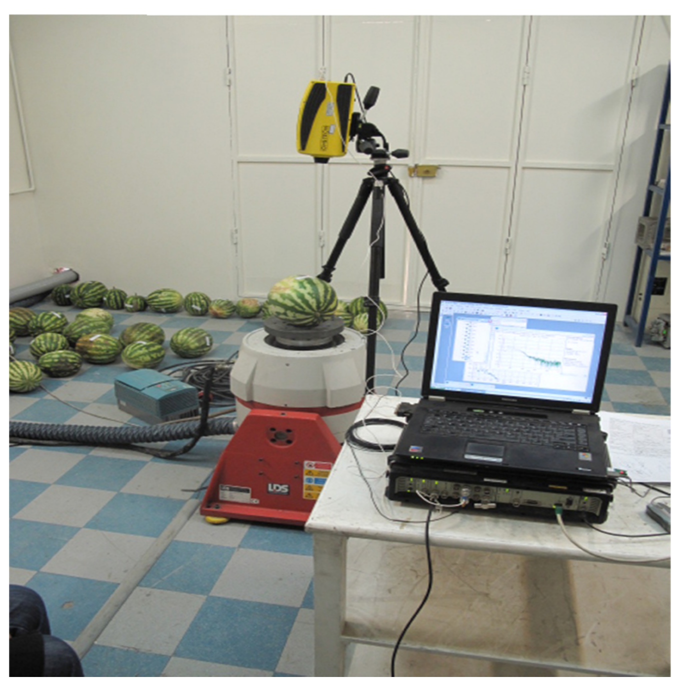

Fig. 2. LDV sensed response of the fruit in upper surface as output signal.