Nondestructive evaluation of watermelon ripeness using LDV

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ABSTRACT

It is very difficult to judge ripeness by outward characteristics such as size or external color and used methods include different limitations. In this study a modern method for ripeness watermelon test using LDV have been presented which hasn’t some limitations. At first the sample is excited by a vibration generator in a frequency range. Applied vibration is measured using accelerometer which is attached in resting place of fruit. Synchronically vibrational response of fruit upside is detected by LDV. This machine irradiates laser beam to selected point in sample upside. Reflected beam from that point received by LDV and finally the vibrational response is measured and related signal is sent to computer. By means of a fast Fourier transform algorithm and considering response signal to excitation signal ratio, frequency response of fruit are analyzed and the desired results are extracted. After nondestructive tests, watermelons were sensory evaluated. So the samples were graded in a range of ripeness based on the usual indicators of quality: sweetness, taste (except sweetness), color and texture and also in terms of overall acceptability (total desired traits consumers). Vibration response study results showed a significant difference between the second resonance frequency and sweetness, taste, color and texture in 1% level does not exist. Meanwhile, a significant relationship between this frequency and overall acceptability, as well as related indicators obtained from $f_0^2 \cdot m^{2/3}$ and color was observed in level of 5%. Significant relationship between phase shift in 200Hz and sensory test results were obtained in 5% level. In 5% level, significant difference between phase shift in 150Hz and taste and overall acceptability as well as between phase shift in 250Hz and color wasn’t shown. This study appeared utilization of mentioned technique for watermelons grading based on their ripeness.

Keywords: Watermelon ripeness, Vibrational response, LDV, Resonance frequency, Phase shift.

INTRODUCTION

Watermelon quality during consumption, mainly depends on its extent of ripeness. Typically optimum quality watermelon fruit for eating have enough sugar, flavor, color and texture. Judging Watermelon ripeness using its apparent properties such as size or skin color is very difficult. The most common way by which people traditionally used to determine the watermelon ripeness is knocking it, and then judge the ripeness using the reflected sound. This method of using sound will create human factor errors; also it may only be a good way for people with much experience [1]. This idea led researchers to study acoustic methods to determine the watermelon ripeness. They received knocking sound using a microphone [2,3,4,1,5,6]. The majority of researchers have not confidence in the results of their reports, also using this method has many limitations and problems for watermelon grading in industrial scale. For example location and number of excitations, microphone distance, angle of hitting and hitter device material could be effective on test results. Environmental conditions like temperature, air pressure and etc. are also effective. Another method is the vibration impulse in which after applied impulse, the generated vibration is measured by the accelerometer. This method also has important limitations that need to paste the accelerometer to the watermelon surface and thus being impractical in the industry, the mass of the accelerometer can also cause an error [7,8]. In addition, using hitting method, excitation energy be focused in a small band on a specific frequency and time this issue causes limitation in determining the exact value of the parameters [9].

In recent years researchers have been studied a new non-destructive vibration technique using LDV technology to test the quality of some fruits. Muramatsu , et al 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 vibration 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. Significant relationship between these two methods obtained in 1200 and 1600 Hz frequencies. [10]. Muramatsu , et al 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 with the LDV
expressed more accurate than accelerometer results [7]. Muramatsu , et al also used the method to conduct some tests and determine fruit texture changes during the ripeness for persimmon, apple and kiwi. In a certain range of frequencies, phase shift as a function of the ripeness would have significantly changed. They also found resonance frequency for all fruit under test is a function of the ripeness [11]. Terasaki , et al were used LDV to assess properties of kiwifruit at different stages of ripeness. They consider two-factor $S = f_n - \frac{2^2 m^{2/3}}{m}$ and $\eta = \frac{(f_2 - f_1)}{f_n}$ where $f_n$ : second peak resonance frequency, $m$: mass of fruit and $f_2$ and $f_1$ at 3 dB below peak resonance are determined. The relationship between $S$ and firmness of kiwifruit was significantly high. $\eta$ also showed well match with soluble solids content. The results showed that the early stages of fruit softening are reflected more favourable by factor $S$ while $\eta$ is more suitable for later stages [12] Sakura , et al conducted some experiments to assess persimmon tissue. They found the data obtained by LDV have significant agreement with the three variables softness, firmness and brittleness for persimmon kept in 60% and 100% humidity storage. These three variables were evaluated by the human senses [13]. Murayama , et al are 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 and were dependent on storage duration and harvest time, except for pears that kept for 4 months in storage temperature of 1°C [14] Taniwaki , et al also conducted a separate investigation to review the trend of change in elasticity index figures from the melon, persimmon and pear after harvest period. They were determined elasticity index from the formula $f_n^2 m^{2/3}$. Resonant frequency $f_n$, the second resonance frequency of sample was obtained using LDV. The samples evaluated using professional's senses and fruits ripeness were evaluated considering features such as appearance, sweetness, firmness and etc. (each separately). Also the overall fruits acceptability was assessed. High correlation between the elasticity index and the mentioned properties were observed. So, researchers could determine the optimum fruit ripeness time, the most appropriate time for eating, according to their elasticity index [9,15,16].

The main goal of this research is: study the vibration response of watermelon using LDV and developing and introducing a nondestructive method to determine the watermelon ripeness.

MATERIALS AND METHODS

In this study 14 watermelons of Crimson Sweet variety, which is one of the varieties for export from the country, were selected for the experiments. In figure 1 a diagram of the desired method is shown. First each watermelon was placed on shaker. Then samples were excited by random signal. This signal generated by computer and were applied on a range of frequencies from zero to 300 Hz. The signals were also amplified by a signal amplifier. For every sample, experiments were repeated in different positions of fruit on shaker. Vibration applied to the fruit by shaker was measured by accelerometer installed in fruit placing position and finally transmitted to the computer. Simultaneously vibration response of fruit top point was measured by LDV (Model Ometron VH300+ made in Denmark). In short, the device emit laser beam to the desired point on top of the sample, the beam reflected from that point, received by the LDV and finally vibration response of the samples (the velocity change due to moving samples considered) were measured and the signals were sent back to the computer. Using a fast Fourier transform algorithm with considering ratio of response signals to exciting signals, frequency response of fruit was analyzed and the desired results was extracted.

Using frequency response curves between the accelerometer and LDV, damping ratio and resonance frequencies of first two vibrational modes were measured. The damping ratio obtained from the relationship $\eta = \frac{(f_2 - f_1)}{f_n}$ where $\eta$: the damping factor, $f_n$:resonance frequency, and $f_1$ and $f_2$ are determined at 3 dB below the resonance peaks. phase shifts between input and output vibrations also were considered in predetermined frequencies (50,100,150,200,250,300).In addition $f_0^2 m f_n^2 m^{2/3}$ in which $m$ is mass (kg) and $f_0$ is the second resonance frequency (Hz), were also calculated using the test results applied in the analysis. These indicators are widely used in mechanical methods to assess the quality of agricultural products.
After determining the vibration response of the samples and measuring their weight, watermelons were sensory evaluated. Seventeen panelists graded the fruits in a range of ripeness based on sweetness, taste (except sweetness), color, texture and also in terms of overall acceptability (total desired traits consumers). The fruit ripeness indices were scored on a scale of 1–5 (1: unripe, 3: ripe, and 5: overripe).

Finally the correlation between LDV-test results and the consumer opinions was determined.
RESULTS & DISCUSSION

Figure 3 illustrates spectrums obtained one sample in some positions. It presents that second resonance peak (128 Hz) has better contrast and less sharpness which can increase the accuracy.

To investigate correlation of achievements extracted second resonance peaks and sensory tests results, P-values were shown in table 1. There is no significant difference between second resonance frequency and sweetness, taste, color, texture at 1% level as well as at 5% for overall acceptability. Index obtained $f_0^2 \cdot m^{2/3}$ has a significant correlation with color at 5% level but significant difference was observed between quality characteristics and damping ratio and also index calculated from $f_{32} \cdot m$ at 1% level.

<table>
<thead>
<tr>
<th></th>
<th>$\eta$</th>
<th>$f_0^2 \cdot m^{2/3}$</th>
<th>$f_0^2 \cdot m$</th>
<th>$f_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweetness</td>
<td>0.396</td>
<td>0.078</td>
<td>0.343</td>
<td>0.008</td>
</tr>
<tr>
<td>Taste</td>
<td>0.148</td>
<td>0.057</td>
<td>0.292</td>
<td>0.005</td>
</tr>
<tr>
<td>Texture</td>
<td>0.297</td>
<td>0.061</td>
<td>0.279</td>
<td>0.007</td>
</tr>
<tr>
<td>Color</td>
<td>0.41</td>
<td>0.022</td>
<td>0.089</td>
<td>0.002</td>
</tr>
<tr>
<td>acceptability</td>
<td>0.357</td>
<td>0.112</td>
<td>0.443</td>
<td>0.012</td>
</tr>
</tbody>
</table>

Table 2 shows p-value of relationship between phase shift in determined frequencies and sensory test.
Table 2 Relationship of results related phase shift and panel test

<table>
<thead>
<tr>
<th></th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweetness</td>
<td>0.546</td>
<td>0.551</td>
<td>0.054</td>
<td>0.009</td>
<td>0.074</td>
<td>0.416</td>
</tr>
<tr>
<td>Taste</td>
<td>0.509</td>
<td>0.351</td>
<td>0.047</td>
<td>0.004</td>
<td>0.051</td>
<td>0.431</td>
</tr>
<tr>
<td>Texture</td>
<td>0.66</td>
<td>0.466</td>
<td>0.087</td>
<td>0.005</td>
<td>0.053</td>
<td>0.307</td>
</tr>
<tr>
<td>Color acceptability</td>
<td>0.138</td>
<td>0.138</td>
<td>0.051</td>
<td>0.006</td>
<td>0.041</td>
<td>0.158</td>
</tr>
</tbody>
</table>

The results shows that phase shifts at 50, 100 and 300 Hz have significant difference with sensory test results but significant relationship was observed between phase shift at 200 Hz and consumer opinions at 0.01 level. There are no significant difference between phase shift of 150Hz and taste and overall acceptability as well as phase shift of 250 Hz and color at 0.05 level.

It seems second resonance frequency and index calculated by $f_0^2.m^{2/3}$ can be used in detection of watermelon ripeness but damping ratio and $f_0^2.m$ aren’t suitable for it. Meanwhile the phase shift at 200 Hz had good relation with quality indicator. Taking into account figure 3 mentioned phenomenon can happens because of existing valley in this part of spectrum. Therefore study of other similar points is suggested. Comparing with other methods, this technique is more accurate without limitations and problems of acoustic method due to distribution of excitation energy in a wide frequencies range and a period of time and lack of additional mass. Also in this method the vibration response of watermelon using LDV is measured without direct contact, accurate and timely that has significant advantage for grading and sorting of the melon for commercial use.

CONCLUSION

Present study demonstrates potential of laser vibrometry for predicting quality of fruit as an online contactless sensing method. Diagnosing poor-quality watermelons in a bottleneck and separate them, this could increase the consumer satisfaction, and providing a plan for using those products is conceivable.

REFERENCES


