Feasibility of a photoelectric sensor technique for nondestructive prediction of granulation disorder in tangerines

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Abstract. Granulation is a physiological disorder in Tangerine (\textit{Citrus reticulata}) that can cause an internal disorder which cannot be determined by visual inspection. A nondestructive technique, which is simple and low cost, that could determine whether an individual fruit suffered from granulation would be of help to the citrus industry. The intensity signal of photoelectric sensor, when light passed through tangerines ‘Keaw Dumnuan’ was investigated and showed that the signal was significantly larger (p < 0.05) for normal tangerines and those suffering from granulation. In order to determine a suitable non-destructive method for detect granulation disorder in tangerines that could be applied commercially, a simple and low cost prototype of this photoelectric sensor technique was developed. A set of 52 fruit were used and their average intensity signal from four measurements was used for discriminant analysis. The cut off value of 61.7 mV was used for classification. If a fruit had the signal intensity equal to or less than 61.7 mV, it had granulation, while fruit that had the signal intensity of more than 61.7 mV was normal. Using this signal intensity discrimination the accuracy of classification was 90.4%. It was also shown that the accuracy of prediction was related to the severity of granulation in each fruit. Therefore, the photoelectric sensor technique was shown to be feasible for use in nondestructively detect of granulation in tangerines and be possibly used in future grading systems.

1. Introduction

Tangerines can be grown in every part of Thailand and are an important commercial favorite fruit. Granulation is a physiological disorder which affects to the quality of citrus fruits, not only in Thailand, but throughout the world. Granulation causes the juice sacs to become enlarged, hard, dry, assume a grayish color, have little free juice tasteless and are unsatisfactory for consuming [1]. Granulation is an internal defect of tangerines and cannot be seen by visual inspection, therefore a reliable, fast and nondestructive technique for their detection would be of benefit to both producers and consumers. Various nondestructive techniques have been used to predict internal defects in fruits. X-ray imaging were used to predict core rot in apples [2] and translucency in pineapple [3], color and firmness measuring to predict pitting damage in peaches [4] magnetic resonance sensor to detect internal browning in apples [5] proton magnetic resonance to determine internal browning and watercore in apples [6], NMR to study on internal browning in pears [7] and MRI and X-ray CT to detect core breakdown in pears [8]. For quality detection of citrus, machine vision and ultraviolet fluorescence was used to detect freeze damage in oranges [9], acoustic impulse response to determine the firmness of mandarins [10], ultrasonics to determine the hydration and firmness of the oranges.
[11], magnetic resonance imaging to detect freeze damage of orange [12] and [13], electronic nose techniques to evaluate mandarin maturity [14] and gas sensors to detect freeze damage in oranges [15]. There are some reports which use various techniques to evaluate granulation disorder of intact tangerines including X-rays [16] and the use of capacitance based techniques [17]. Basic principles of materials describe that materials are made up of molecules and molecules are composed of atoms that are joined together by bonds. The most common bonds in agricultural and food materials are joined between carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and phosphorus (P) atoms therefore molecules such as cellulose, oil, protein, starch and water contain many atomic groupings such as C-H, N-H and O-H. Whenever materials are irradiated by energy from light, this energy is absorbed by molecules in the materials. The molecules are in different forms such as protein, water, starch, oil, fiber and others, which will absorb different energy levels based on their characteristics [18]. By this fundamental, when normal tangerines and granulation tangerines are irradiated by light energy, they shall absorb different level of energy. In this case, it can be a measure of the difference of energy absorbance by the quantity of light intensity signal that passed through tangerines.

Light technology techniques, such as near infrared spectroscopy (NIRS), have been used to predict the internal qualities of agricultural and food products such as sweet corn [19], tomato [20], marian plum [21] and [22], sweet tamarind [23], mangosteen [24] and [25], pineapple [26] and [27], limes [28] and [29], guava [30], hen’s eggs [31] and [32], pork meatball [33] and jelly [34]. Good results for prediction were obtained from the NIRS technique but it is quite expensive. A photoelectric sensor is a lower cost and is simple to use, therefore this technique was evaluated for the detection of granulation. Photoelectric sensors, such as phototransistors, photocells, light dependent resistors (LDR), photodiodes, respond to light in the visible and infrared radiation range [35]. This technique is fast, simple and nondestructive and therefore can be possibly applied to an on-line grading system. In a recent report, the photoelectric sensor was combined with density measurements for predicting the freshness of hen’s eggs [36]. Therefore, we decided to study the photoelectric sensor technique for nondestructively prediction of the granulation disorder in tangerines.

2. Materials and Methods
Tangerines cultivar ‘Keaw Dumnuan’ were purchased from a local fruit market in Thailand. Fifty two fruit were selected that were similar in size and without blemishes. Their maximum diameter and minimum diameters were measured with a vernier caliper (Auto-lock vernier caliper, Long Jer, Taiwan) and their mass with an electronic digital balance (WANT, Jiangsu, China). A low cost prototype photoelectric sensor was designed and developed in order to measure the intensity signal of each fruit as shown in figure 1. The transformer (220V-6V), light source (50W halogen lamp), photoelectric sensor (KODENSHI, silicon phototransistor, ST-325, spectral sensitivity between 500-1,050 nm and the peak wavelength at 880 nm) and a fruit holder were assembled in a special box, which was designed with a door for controlling the light. Each sample was placed on the fruit holder and the light source was switched on so that transmitted light passed through the fruit to the photoelectric sensor. Four measurements were taken on each fruit (four points in the horizontal position at the equator in every 90o rotation). The average signal was calculated and used for analysis. After measurement, each sample was peeled and inspected and any internal granulation disorder recorded by visual inspection and divided to a set of sound samples and a set of granulated samples. The set of granulated samples were then divided into two groups based on the severity of granulation by measuring the percentage of granulated area on the surface of each segment. This measurement was referred to as the index of severity. On this basis each fruit was classified into one of three groups: 0% granulation, 1-50% granulation and 51-100% granulation. Statistical analysis was carried out with R Statistical Software using ANOVA and Duncan’s Multiple Range Test where appropriate at p < 0.05.
3. Results and Discussions

Sound samples and granulated samples were separated by visual inspection as shown in figure 2. The characteristic of the fruit used and intensity signal are shown in table 1. There were twelve sound fruit and forty granulated fruit. The signals from the fruit in sound group were significantly higher ($p < 0.05$) than those in the granulation group (figure 3). This difference was probably due to the acquired intensity signal that was measured from transmitted light that had passed through samples and implies that the tangerines with granulation absorbed higher light energy than those of sound tangerines.

![Figure 2. Samples of tangerine with different internal quality (a) sound (b) granulation.](Image)

Table 1. Characteristics of the sample ($n = 52$) of tangerines used for testing the photoelectric sensor.

|                | Range       | Average |
|----------------|-------------|---------|
| Mass (g)       | 73.5-204.9  | 134.2   |
| Diameter (mm)  | 56.9-77.0   | 65.3    |
| Signal intensity (mV) | 25.0-173.0  | 50.6    |
Figure 3. Signal intensity of tangerines with or without granulation, where sound (0% granulation) and granulation (1-100% granulation).

The intensity signal of tangerines was found to be related to the severity of granulation (figure 4) where the signals of sound fruit were significantly higher ($p < 0.05$) than the signals from fruit with 1-50% granulation, which, in turn, were significantly higher ($p < 0.05$) than the signals of 51-100% fruit.

Figure 4. Box plot of signal intensity of tangerines with different levels of granulation.

A box plot of the intensity signal in the group of sound compared to the group of fruit suffering granulation were investigated and the cut off value of 61.7 mV was defined, which was the mean value between a value at 90% percentile of normal group and a value at 10% percentile of granulation group. Therefore, for discrimination analysis, if the intensity signal of fruit was equal or less than 61.7 mV, those fruit was assumed to be the granulation fruit. If the intensity signal of fruit was higher than 61.7 mV, those fruit was assumed to be the sound fruit. The results of discrimination analysis showed that the accuracy for prediction in sound group was 83.3% the accuracy for prediction in granulation group was 92.5%, with an overall accuracy of 90.4% (table 2). It had higher accuracy when compared to the use of capacitance based techniques with the accuracy of 75.6% in the previous study.
Table 2. Signal intensity classification for tangerines, with or without granulation, using a threshold value of 61.7 mV (>61.7 mV= sound tangerines with no granulation; <61.7 mV= tangerines with granulation).

| Acquisition | Number of sound tangerines | Number of granulation tangerines | Total Number of tangerines | Classification accuracy (%) |
|-------------|----------------------------|---------------------------------|-----------------------------|----------------------------|
| Total       | 12                         | 40                              | 52                          |                            |
| correct     | 10                         | 37                              | 47                          | 90.4                       |
| Incorrect   | 2                          | 3                               | 5                           |                            |

4. Conclusion
A low cost prototype photoelectric sensor, which had spectral sensitivity between 500-1,050 nm, was developed, assembled and used to measure the intensity signal through tangerines to determine whether or not they suffered from the internal physiological disorder called granulation. Results showed 90.4% accuracy in the measurement and also some measure of the intensity of granulation within individual fruit, which indicates that there is potential for developing this prototype for commercial use in commercial online grading of citrus fruit.

5. References
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