Classification of Pomelo Maturity Based on Acoustic Response and External Peel Properties

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ABSTRACT

This research investigated the maturity assessment of pomelo using acoustic properties obtained from an impact of fruit, optical properties of the peel and variables related to oil glands from peel images. Pomelo samples were harvested at 5.5, 6.0 and 6.5 months after anthesis. All non-destructive variables were used to build qualitative models with partial least squares discriminant analysis. The classification model based on the non-destructive variables showed that fruits could be separated into immature, early-mature and late-mature groups with an accuracy of 96.7%. The important variables contributing to the classification were the impact response based on first, second, and third order of resonant frequency and the difference of green and blue colour between the oil gland and the peel.

Key words: Pomelo, Maturity, Acoustic response, Oil gland, Optical properties

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INTRODUCTION

Pomelo (Citrus maxima Merr.) is one of top export fruits from Thailand due to its health properties. Properly mature pomelos guarantee optimal eating quality. Several subjective techniques have been used to determine the maturity of pomelo. At present, farmers employ the number of days after anthesis to identify harvestable pomelos (Verheij and Coronel, 1991). Visual inspection of the peel is also used to assess the fruit maturity. It is known that when fruit is mature, the oil glands, which are spread all over the peel, become more prominent and shinier, and make the peel look brighter in appearance (Chomchalow, 1984). In addition, the oil glands of immature pomelo are small and tightly packed. However, mature pomelo shows larger and well separated oil glands on the peel (Nissen et al., 2008). Research has been undertaken to determine the objective parameters for maturity assessment of pomelo based on a change in the oil gland characteristics with maturity (Wattanavichean and Aroonyadet, 2003). The parameters that quantified density and the size of the oil glands were found to correlate (correlation coefficient of 0.77) with the maturity of the pomelo as referenced by the ratio of the soluble solids content and acidity.

The overall colour of the peel of pomelo is also used by harvesters as one of the subjective assessment criteria for detecting maturity (Verheij and Coronel, 1991). There have been a number of researchers who investigated the relationship between the fruit colour measured by instrument and maturity. The colour properties of fruit have been reported for the assessment of the palm fruit ripeness. The pixel value of images of the palm fruit, which was measured in terms of the hue, was shown to relate to the stages of ripeness in terms of the oil content of the mesocarp for fresh fruit bunches (Razali et al., 2009).

Fruit quality can be assessed objectively by a parameter related to the resonant frequency with compensation for fruit size variation. The acoustic excitation method is widely used as it can be applicable to on-line sorting. The acoustic response of pomelo harvested at four stages of maturity was found to be suitable for the estimation of the ratio of the soluble solids content to acidity with a correlation coefficient of 0.79 (Terdwongworakul et al., 2009).

There have been no reports on the application of multivariate data analysis in combining the acoustic properties, overall peel colour and oil gland characteristics for the assessment of the maturity stages of pomelo. Thus, the objective of the present study was to develop a non-destructive model.
based on the acoustic properties, the optical properties of peel and the oil gland characteristics for classifying pomelo into different stages of maturity.

**MATERIALS AND METHODS**

1. **Samples**

   Pomelo samples of the “Kao Namphueng” variety were harvested from commercial orchards at three stages of maturity. A set of 32 fruit was picked every two weeks from each harvest which provided a total of 96 fruit samples. The first harvest began when the fruit growth was 5.5 months after anthesis. All samples were transported to the laboratory within two hours and were kept for acclimatization at 25°C for 24 hours prior to all measurements.

2. **Non-destructive evaluation**

   2.1 **Optical properties of the peel surface**

       The peel surface of each individual fruit was measured for the optical properties using an spectrophotometer (Spectro-guide sphere gloss, model CD-6834 BYK-Gardner GmbH, Geretsried, Germany) with D65 illumination and 10 degree observer settings. The measurements were taken at four positions on the equatorial section, each 90° apart. Each measurement was repeated three times to record an average of the four CIELAB colour parameters -L*, a*, b* and gloss value at 60°.

   2.2 **Oil gland characteristics by image processing**

       Three properties of the oil glands on the peel were determined from the peel images namely, the oil gland area size (OGS), the oil gland density (OGD) and the colour differences between the oil gland and the peel surface in colours of green (delG), red (delR) and blue (delB). The reason that the colour difference was measured was that the colour of the peel and the gland alone may not optimally represent the peel characteristics because of sunlight variation in different position of the fruit on the tree. Consequently, the colour difference could eliminate the sunlight variation in the oil gland colour.

       In the image acquisition process, each fruit was placed inside a black box and was illuminated by four light-emitting diode lamps (3.5 W, 5000 K, 220 V) installed in each corner of the box to provide a uniform light intensity (Jarimopas and Jaisin, 2008). An image was photographed from each location on the fruit surface (same position as the measurement of the optical property) using a digital camera (Canon PowerShot A2200, Tokyo, Japan) mounted 100 mm. in front of the fruit.

       The image processing was performed on each image using the public domain software package Image J (Ver. 1.36, developed by Wayne Rasband, National Institute of Mental Health, Bethesda, MD, USA) and started from cropping each image to a size 1x1 cm² to reduce any effect of
fruit curvature (Fig. 1a) (Wattanavicheanand Aroonyadet, 2003). The RGB image was then transformed to an 8-bit gray-scale image (Fig. 1b) and the detail enhancement was performed using a homomorphic filter to remove non-uniform illumination (Fig. 1c). A binary image was created using the minimum cross entropy method (Li and Lee, 1993) to define the threshold for the image segmentation. Median filtering was then carried out to remove noises in the binary image (Fig. 1d). A morphological watershed was applied to separate the touching oil glands.

![Figure 1](image)

Figure 1 Original image (a), gray-scale image (b), image after homomorphic filter (c) and binary image using the minimum cross-entropy thresholding (d).

The OGS in the processed image was determined by summing the number of pixels of the intact oil glands (visibly seen as full glands) and dividing the summation by the number of the intact glands. The number of the oil glands in the processed image with an area of 1 cm², which represented the OGD, was determined by summing all areas of the oil glands that appeared in the image and dividing by the average oil gland area size for normalization (Wattanavicheanand Aroonyadet, 2003).

In addition to the OGS and OGD, the value of the colour difference between the oil gland and the peel surface was also extracted from the image. Each image was further processed to obtain the oil gland and the peel surface images by masking the original image with the binary image. Then the oil gland and the peel images were separated into the red, green and blue images. The red image of the peel was subtracted from the red image of the oil gland to quantify the colour difference value of the red colour (delR). Similarly, delG and delB were also quantified from the corresponding green and blue images respectively. The average parameters from the four images after analyses using data from each fruit were used to represent the oil gland characteristics of each fruit.
2.3 Acoustic response measurement

The fruit response to an acoustic impulse carries information related to the firmness of the whole fruit. The acoustic impulse response of each fruit was conducted and the impulsesound was recorded by a microphone installed diametrically opposite to the tapped point (Terdwongworakul et al., 2009). The sound signal in time domain was transformed into the frequency domain with a fast Fourier transform algorithm developed in C++.

The acoustic response of each fruit was characterized by three distinct crests in the frequency spectrum which were designated as $f_1$, $f_2$ and $f_3$ for the first, second and third resonant frequencies respectively. Each fruit was subjected to four measurements obtained at equally spaced positions on the equatorial line. The stiffness coefficient was computed from $f_i^2m^{2/3}$, where $f_i$ is the $i^{th}$ order frequency (Hz) and $m$ is the fruit mass (g), to normalize the variation of the fruit mass (Barriga-Téllez et al., 2011).

3. Destructive evaluation

3.1 Total soluble solids assessment

Four segments of flesh were removed from the fruit. The juice was extracted from the four segments and filtered. The soluble solids content (SSC) was determined from the juice using a digital refractometer (PR-32, Palette Series, Atago Co., Ltd., Tokyo, Japan). Threereplications were used to calculate the average SSC from each fruit.

3.2 Titratable acidity assessment

The titratable acidity (TA) was also determined from the same juice by titration of 2 ml. juice with 0.1 N NaOH. The quantity of NaOH at the point of colour change in a phenolphthalein indicator was used to calculate total acidity (%) based on the citric acid equivalent. The average of three repeated measurements was determined for each fruit.

4. Classification analyses

The non-destructive variables were taken as classifying variables in the development of the classification models. The samples in each group of maturity were divided into a sub-calibration set (21 samples) and a sub-prediction set (11 samples) each with a similar distribution of the SSC. The sub-calibration and the sub-prediction sets of each maturity group were then combined to form the calibration set and the prediction set respectively. The calibration set was submitted to partial least squares discriminant analysis (PLSDA) using the Unscrambler package (version 9.8, Camo, Oslo, Norway) to develop classifying models. The PLSDA model was developed from data in the calibration set and the optimal number of factors was determined by cross validation of the same calibration set.
The classification correctness of the models was then assessed on the prediction set. The classifying PLSDA model was simplified by reducing the number of the non-destructive variables in the model. A stepwise procedure was performed to statistically select the optimal variables for the simplified model.

RESULTS AND DISCUSSION

1. Partial least squares discriminant analysis

The performances of the PLSDA models for classifications based on non-destructive variables are shown in Table 1. The first row of Table 1 shows the performance of the first PLSDA model created using all non-destructive variables for the classification of the samples of the prediction set into three maturity groups. The overall accuracy was 96.4%. The samples in the late-mature group were best correctly classified (100%) whereas those in the immature group appeared to be least correctly sorted (93.3%). The PLSDA model for predicting the immature, early-mature and late-mature group required five, seven and four latent variables (Table 1), respectively, to capture the necessary variance in the data.

Table 1 Classification matrices showing the comparative performance of classifications of the samples in the prediction set into three maturity groups using PLSDA models developed using non-destructive variables

<table>
<thead>
<tr>
<th>Predictor variable</th>
<th>Correctly classified pomelo (%)</th>
<th>Overall accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b*, f1 m 2/3, f2 m 2/3, OGS, delR, delG and delB</td>
<td>96.7 (6)</td>
<td>96.4</td>
</tr>
<tr>
<td>L*, a*, b*, gloss, f1 m 2/3, f2 m 2/3, f3 m 2/3, OGS, OGD, delR, delG and delB</td>
<td>93.3 (5)</td>
<td>96.7 (7)</td>
</tr>
</tbody>
</table>

Notes: a) f1 m 2/3: stiffness coefficient (where f is the ith resonant frequency and m is the pomelo mass), L*: luminosity, a*: red-green chromaticity, b*: blue-yellow chromaticity, OGS: Oil gland area size, OGD: Oil gland density, delR: Red colour difference between the oil gland and the peel, delG: Green colour difference between the oil gland and the peel, delB: Blue colour difference between the oil gland and the peel.

b) Numbers in parenthesis indicate the number of latent variables used in the PLSDA model.
2. Simplification of PLSDA model

Further study was undertaken to simplify the classification model based on a reduction in the number of the predicting variables. In the selection of the optimal variables, all non-destructive variables were submitted for discriminant analysis using the stepwise method in the SPSS software (version 9.0, Chicago, IL, USA). The stepwise method describes a process to enter and remove a variable into the model by statistically testing the significance of the considered variable as a predictor in the model (Tabachnick and Fidell, 1996).

The stepwise method selected $b^*, f_1^{2m^{2/3}}, f_2^{2m^{2/3}}, f_3^{2m^{2/3}}, OGS, delG$ and $delB$ as the classifying variables. These selected variables were then used to build PLSDA models for classification of the stage of maturity. The bottom rows of the results in Table 1 show the classification performance of the models based on the selected variables. The accuracy (96.7%) of the simplified model was similar to that of the model using all variables (96.4%).

All non-destructively measured variables used in the investigation were originated from the three different groups of characteristics—the peel optical properties, acoustic response and oil gland characteristics. In consideration of the variables selected by means of the stepwise method, at least one variable from each group was chosen statistically. This justified the combination of these three groups of characteristics for the classification.

CONCLUSION

The pomelo stage of maturity could be evaluated by subjective means of non-destructive measurements acquired from acoustic response and external peel properties. The model created using all non-destructive variables could classify the stage of pomelo maturity with an accuracy of 96.4%. The stepwise method was used to simplify the classification model by reducing the number of the predicting variables. The performance of the simplified model created using variables from stepwise selection was 96.7%. The variables selected by mean of the stepwise method were originated from the three different groups of characteristics.

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