Assessment of Pomelo Maturity using Optical Properties and Characteristics of Its Peel

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***Abstract*—Pomelo maturity was evaluated based on peel optical properties and characteristics. Four stages of maturity were harvested at 5.5, 6.0, 6.5 and 7.0 months after anthesis. All optical parameters and peel related variables were used to develop a multivariate classifying model with the discriminant analysis. The accuracy of classifying all samples into immature, early-mature, late-mature and mature groups was 83.3%. The most distinguishing difference between a group of the immature and early-mature pomelos from a group of the late-mature and mature pomelos was a variation of green colour between the oil gland and the peel surface.**

***Index Terms*—pomelo, peel, oil gland, Image**

I. Introduction

Pomelo (Citrus maxima Merr.) is an important export fruit from Thailand owing to its health characteristics. Optimal eating quality of pomelos is dependent on the fruits' maturity at harvest. A number of subjective parameters have been utilized to assess the maturity of pomelos including peel characteristics and appearance [1]. It is recognized that the oil glands of mature fruit, distributed across the entire surface of the peel, develop to be shinier and more prominent, brightening the appearance of the peel [2], [3]. There have been a number of researches that attempted to attain the objective parameters as related to external appearance for maturity evaluation. A correlation coefficient of 0.77 was found for the size and density of the oil glands and the maturity of the fruit (defined by the ratio of the soluble solids content and acidity) [4]. The peels hue may be a more useful external characteristics for determining maturity than brightness. Previously, the color properties of the palm fruits were investigated for the assessment of ripeness. The hue values of image pixels of palm fruits were found to relate to the stages of ripeness and mesocarp oil content [5]. There have been few reports on the assessment of pomelo maturity based on the peel properties. The objective of this present investigation was to create a multivariate pomelo maturation classification model based on peel properties including peel hue.

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II. Materals and Methods

A. Samples

Four maturity stages of pomelos of the 'Kao Namphueng' variety were harvested from a commercial plantation, Nakhon Pathom province, Thailand. Given the first harvest at 5.5 months after anthesis (MAA), four different stages of maturity were designated: immaturity (5.5 MAA), early-maturity (6.0 MAA), late-maturity (6.5 MAA) and over-maturity (7.0 MAA). A set of 32 fruits was collected every two weeks (128 fruit total). All harvested samples were immediately transported to the laboratory within two hours and were stored for acclimatization at 25°C for 24 hours preceding subsequent measurements.

B. Peel Feature Measurements

Optical properties of the peel surface: The peel surface of each individual pomelo was quantified for four CIELAB color parameters (L*, a* and b*) and gloss value at 60°using a spectrophotometer (Spectro-guide sphere gloss, model CD-6834 BYK-Gardner GmbH, Geretsried, Germany). The quantifications were taken at four positions on the equatorial section, each 90° apart.

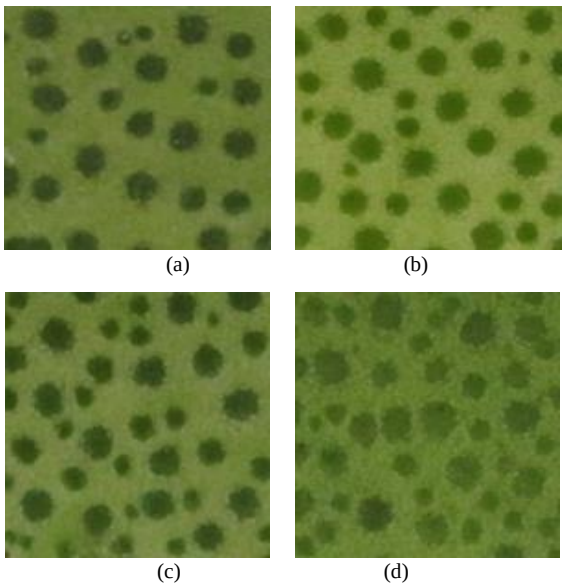

Figure 1. Cropped images of pomelo samples at (a) 5.5 MAA, (b) 6.0 MAA, (c) 6.5 MAA and (d) 7.0 MA (MAA = Months after anthesis).

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Oil gland features by image processing: Each fruit was positioned inside a box with black lining and was irradiated by four light–emitting diode lamps (3.5W, 5000 K, 220 V). The lamps were attached to each corner of the box to enable a uniform light intensity and minimize shadows. An image size of 3072×2304 pixels was photographed from each location on the pomelo surface using a digital camera (Canon PowerShot A2200, Tokyo, Japan) installed 100 mm in front of the fruit. Each image was then cropped to a size of 1×1 cm^2 prior to analyzes to minimize any effect of fruit curvature (Fig. 1) [4].

The oil gland area size (OGS), the oil gland density (OGD) and the color difference between the oil gland and the peel surface in color of red (ΔR), green (ΔG) and blue (ΔB) were quantified from images of the peel by means of image processing. Lacunarity analysis was also applied for each peel image to quantify how the oil glands filled the surface.

Image processing was achieved using the public domain software package Image J (Ver. 1.36, available at http://www.rsb.info.nih.gov/ij; developed by Wayne Rasband, National Institute of Mental Health, Bethesda, MD, USA). RGB images were converted to an 8-bit gray scale image and a binary image was then generated using the minimum cross entropy method [5]. The touching oil glands were separated by application of a morphological watershed. The OGS of the peel image was quantified by dividing the number of pixels of the intact oil glands by the sum of the intact glands. The OGD in the cropped image was computed by dividing the sum of all oil gland areas that were visible in the image and by the average oil gland area size for normalization [4]. For extraction of ΔR, ΔG and ΔB values, each original image was initially masked with the binary image to obtain the oil gland and the peel surface images. Then the oil gland and the peel surface images were divided into the red, green and blue images. The images of the oil gland were subtracted by the corresponding images of the peel surface to determine the values of color difference. The averaged parameters from the four images of each sample were used for further analyzes.

In addition, lacunarity analysis was applied to quantify changes in the oil gland distribution with respect to different growth stages. The lacunarity describes the distribution and heterogeneity of the oil glands on the peel surface [6]. For the image size of $M \times M$, lacunarity ($L(r)$) was calculated as follows:

$$L(r) = \frac{(N(r) \times Q_2)}{Q_1^2} \quad (1)$$

$$N(r) = (M - r + 1)^2 \quad (2)$$

$$Q_1 = \sum_i p(i, r) \quad (3)$$

$$Q_2 = \sum_i p(i, r)^2 \quad (4)$$

where a box of size $r \times r$ was glided from the top-left corner to the bottom-right corner of the image with i and $p(i, r)$ representing a position in the image and the number of pixels in the i^{th} box respectively. The width r of the gliding boxes were selected as 2, 4, 8, 16, 32, 64, 128 and 256 pixels.

C. Total Soluble Solids Measurement

Four segments of flesh were taken from each sample and the juice was extracted. The filtered juice was then determined for the soluble solids content (SSC) using a digital refractometer (PR-32, Palette Series, Atago Co., Ltd., Tokyo, Japan). The average of three replicates was used for further analyses.

D. Data Analyzes

Maturity effect: Mean values of each variable were statistically tested to investigate the effect of maturity based on one-way analysis of variance with a completely randomized design.

Discriminant analysis: The peel related variables were used as classifying variables to develop the classification models. In each maturity group, each sample was assigned into a sub-calibration set and a sub-prediction set with an analogous distribution of the SSC. The sub-calibration and the sub-prediction sets of each group of maturity were then pooled into the calibration set and the prediction set. The calibration set was used to build a classifying model by discriminant analysis (SPSS version 9.0, Chicago, IL). The discriminant analysis is a multivariate technique used for creating linear functions of multiple variables that promotes the maximum difference between two or more classes and minimizes variation within each class. The accuracy of the model for classification was evaluated with the samples in the prediction set.

III. Results and Discussion

A. Effect of Maturity Stages on the Measured Variables

Optical variables: Statistical test results of the one way analysis of variance are displayed in Table I. The significant effect of the maturity class on the ΔG was maximum with the ratio of the variation between groups to the variation within groups (F value) equal to 43.34 at 95% confidence. As the fruit matured, the ΔG declined continuously. This implied that the difference in green components of the oil gland and the peel color was less as the fruit matured. The result was in agreement with the report that the pomelo peel and the oil glands appeared to be brighter and shinier upon ripening [1]. The ΔG value was a relative parameter compared to other color properties and probably compensated for the variation due to position of the fruit on the tree [7].

Among the optical properties of the peel, yellow color represented by the positive b* value was influenced most by the variation in maturity (F = 10.44 in Table I). The b* value increased from 5.5 to 6.0 MAA and then began to drop until 7.0 MAA. The gloss value reduced consistently to 6.5 MAA and remained constant.

Peel related variables: A continuous reduction of the OGS was apparent from 5.5 to 6.5 MAA before

increasing to 7.0 MAA. The change in the OGD was in contrast with that in the OGS. The OGD rose to 6.5 MAA before decreasing. These trends of change in the OGS and the OGD were similar to the previous findings [4].

TABLE I. EFFECT OF MATURITY STAGE ON CHANGES IN MEASURED VARIABLES

Parameter	Time after anthesis (months)			
	5.5 Immature pomelo	6.0 Early-mature pomelo	6.5 Late-mature pomelo	7.0 Over-mature pomelo
SSC (10.39)**	13.70[a]*	14.63[b]	14.30[b]	13.26[a]
L* (4.94)	55.22[a]	57.28[b]	57.35[b]	56.28[ab]
a* (1.41)	-6.75[n.s.]	-7.06[n.s.]	-6.60[n.s.]	-6.79[n.s.]
b* (10.44)	27.86[a]	31.27[c]	30.43[bc]	29.49[b]
Gloss (5.84)	2.42[b]	2.16[a]	2.02[a]	2.02[a]
OGS (11.55)	0.78[c]	0.69[b]	0.61[a]	0.66[ab]
OGD (12.70)	33.86[a]	38.75[b]	44.16[c]	43.56[c]
ΔR (38.11)	42.10[c]	40.91[c]	34.97[b]	32.37[a]
ΔG (43.34)	41.12[c]	38.58[b]	31.70[a]	29.95[a]
ΔB (9.75)	25.69[b]	24.52[b]	26.08[b]	22.01[a]
L(2) (4.80)	3.86[c]	3.81[bc]	3.67[ab]	3.57[a]
L(4) (5.58)	3.64[c]	3.57[bc]	3.42[ab]	3.34[a]
L(8) (7.25)	3.24[b]	3.16[b]	2.99[a]	2.95[a]
L(16) (10.88)	2.52[b]	2.41[b]	2.25[a]	2.25[a]
L(32) (13.76)	1.51[c]	1.43[b]	1.33[a]	1.38[ab]
L(64) (6.53)	1.05[c]	1.04[ab]	1.04[a]	1.04[b]
L(128) (9.87)	1.01[n.s.]	1.01[n.s.]	1.01[n.s.]	1.01[n.s.]
L(256) (15.62)	1.00[n.s.]	1.00[n.s.]	1.00[n.s.]	1.00[n.s.]

* a, b and c indicates a significant difference at $p < 0.05$.

n.s. indicates no significant difference at $p < 0.05$.

** The number in parenthesis following the properties was the ratio of the variation between groups to the variation within groups (F value).

SSC = Soluble solids content (°Brix).

OGS = Oil gland area size (mm^2), OGD = Oil gland density (No. of glands/cm^2) and L(i) = Lacunarity with a gliding box of size i×i.

Relevant to the lacunarity values, all values with different size of the gliding box showed a decreasing trend with respect to an increase in maturity (Table I). Only the lacunarity with the box size of 32 pixels (L(32)) showed a continuous decrease from 5.5 to 6.5 MAA and then an increase in value at 7.0 MAA. This variation of L(32) was comparable to the change in the OGS. The reduction in the lacunarity suggested that as the pomelo became more mature, smaller gaps between the oil glands were dominant. In addition, lower lacunarity value meant there was less heterogeneity of the oil gland distribution in the image [8].

B. Classification Model

Table II shows the performance of the classifying model from the discriminant analysis. The overall accuracy was 83.3% with the over-mature pomelo being classified most correctly (100%). Immature fruits, on the other hand, were the least likely to be accurately classified (60% correctly classified). The factorial plot of both the first and second discriminant functions illustrated the separation of the maturity classes along the first two discriminant functions (Fig. 2a) which explained the combined variance of 88.6% and along the discriminant functions 1 and 3 with explained variance of 80.5% (Fig. 2b).

TABLE II. CLASSIFICATION RESULTS OF THE DISCRIMINANT ANALYSIS

Correctly classified pomelo (%)				Overall accuracy (%)
Immature pomelo (5.5 MAA)	Early-mature pomelo (6.0 MAA)	Late-mature pomelo (6.5 MAA)	Over-mature pomelo (7.0 MAA)	
60	90	91.8	100	83.3

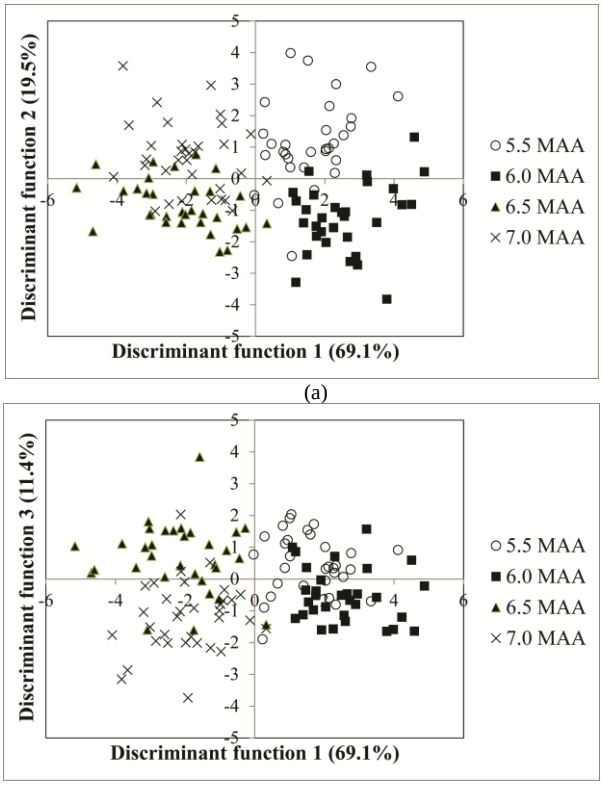

Figure 2. Scatter plot of pomelo samples at four maturity stages with respect to (a) discriminant function 1 and 2 and (b) discriminant function 1 and 3

The structure matrix in Table III depicts the simple correlation of each variable with the discriminant functions. Upon consideration the structure matrix along with Fig. 2, the first discriminant function was able to pick up the difference between a group of 5.5 and 6.0 MAA and a group of 6.5 and 7.0 MAA. The ΔG and a* (Table III) contributed to the separation of these two groups. This meant a change in the green color or especially the difference in the green color between the oil gland and the peel could be used to separate the immature and early-mature fruit from the late-mature and over-mature fruit.

From Fig. 2a and Table III, the difference between the immaturity and early-maturity was most sensed by L(128) in association with the discriminant function 2. This implied that the heterogeneity in the pattern of the oil gland distribution was evident when the pomelo

developed from the immature stage to the early-mature stage.

Fig. 2b showed that the development from the late-maturity to full maturity was associated with the discriminant function 3, which was related greatly to the ΔB (Table III) or the difference in blue color between the oil gland and the peel surface.

TABLE III. CORRELATION COEFFICIENTS BETWEEN THE DISCRIMINANT SCORE AND VARIABLES

Parameter	Discriminant function		
	1	2	3
ΔG	**0.438**	0.191	0.422
a*	**-0.188**	-0.017	0.068
L(128)	0.047	**0.443**	-0.226
L(32)	0.270	**0.397**	0.173
b*	0.155	**-0.347**	-0.080
L(64)	0.177	**0.322**	0.015
OGS	0.229	**0.279**	0.154
L*	0.108	**-0.261**	-0.002
Gloss	0.120	**0.195**	0.123
L(256)	-0.059	**0.123**	0.052
ΔB	0.029	-0.140	**0.480**
ΔR	0.399	0.048	**0.412**
OGD	-0.271	-0.273	**-0.357**
L(8)	0.221	0.182	**0.303**
L(4)	0.193	0.138	**0.295**
L(16)	0.262	0.277	**0.293**
L(2)	0.177	0.117	**0.289**

IV. CONCLUSIONS

Detection of the pomelo maturity can now achieved by multivariate analysis of peel optical properties and characteristics. A classifying model based on the discriminant analysis offered an overall accuracy of 83.3%. The difference in the green color between the oil gland and the peel surface was the key determinant in separating the immature and early-mature pomelos from the late-mature and over-mature pomelos. When the fruit developed from the immature to the early-mature stage, less heterogeneity in the distribution of the oil glands (indicated by a lower lacunarity value) was evident. The difference in blue color between the oil gland and the peel surface was apparent as the pomelos progressed from the late-mature stage to the over-mature stage. The results of this study showed the variables related to the oil gland and the peel could be applied to evaluate the maturity of pomelo fruits with satisfactory accuracy.

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