Application of Image Analysis for Determination of Mangosteen Density

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***Abstract*—Density is used to predict the internal quality of various fruits. For mangosteen, a floating technique based on density is used routinely as the sorting system for quality classification but it is inconvenient and time consuming. The applied image analysis technique was studied to evaluate the density of mangosteen. RGB digital 2-D pictures were converted to binary images. Pixels of mangosteen from eight pictures taken using different views were averaged and compared to the pixels of a reference circle plate. From the image analysis, the average volume of mangosteen was first calculated and then the average density of mangosteen was determined. The predicted densities of 80 fruits using the image analysis technique were compared with the measured densities and obtained a high correlation coefficient (R=0.91). The results showed the image analysis technique could be applied for nondestructive sorting to evaluate the internal quality of mangosteen based on the predicted density.**

***Index Terms*—nondestructive, image analysis, density, quality, prediction**

I. Introduction

Density is an important index for the quality evaluation of fruits and is often related to the internal quality in fruits such as internal breakdown, water distribution, decay and insect infestation [1]. Density is also correlated to the soluble-solids content (SSC) in many kinds of fruit. Knowledge of physical properties like density is fundamental to the design and optimization of processing operations in the fruit puree industry [2], [3]. Fruit sorting obtained high accuracy when density was used for SSC prediction of grape berries [4]. Density could be used to estimate the dry matter (DM) and SSC of kiwifruit with high correlation [5]-[7]. Furthermore, density has been found to be related to both hollowness and the SSC in watermelon [8]. It was also used as an important parameter to detect internal damage in fruit [9].

Mangosteen (*Garcinia mangostana* L.) is considered as the queen of tropical fruits. Thailand is the largest producer in the world [10]. The postharvest quality of mangosteen is affected by several internal factors such as translucent flesh, the existence of gamboges and the hardening pericarp as well as by external factors like colour, shape, size, skin blemishes, latex staining and insect damage. These factors are considered in determining the quality of mangosteen for consumer acceptance and satisfaction. Internal disorders cannot be identified by visual evaluation but a recent report indicated that internal defects correspond to the density of mangosteen [11]. The floating technique is applied as a sorting method in order to predict internal defects in mangosteen based on differences in density. However, this approach makes the products wet and requires additional processes such as water treatment, drying and a handling system which are inconvenient and time consuming. Hence, a simple and non-destructive technique to predict the internal quality of mangosteen is required.

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Mass is normally used to classify the size of fruits. Good appearance and the absence of defects certainly contribute to consumer preference [12]. Visual sorting is normally used by the consumer to determine the quality of products. An image analysis technique as well as visual inspection can be applied for quality evaluation and the classification of fruit and vegetables. Recent studies have presented the use of image analysis techniques to evaluate fruit attributes such as skin defects in citrus fruits [13], firmness and soluble solids content of apples [14], internal quality of blueberries [15], bruises on Chinese bayberries [16], bruise on kiwi fruits [17], fungal infection of date fruits [18], fruit fly infestation in mangoes [19], size and shape features of walnuts [20], size of grapevine berries [21] and maturity of persimmon fruits [22].

The volume of a fruit is also one of the key parameters to assess its quality. Fruit volume has been applied to estimate the relationship between the fruit expansion rate and physiological disorders in bell pepper fruit [23]. Reports showed that the volume of agricultural products could be predicted by the ellipsoid approximation method using digital images for watermelon [24], barley grain [25], kiwifruit [26] and citrus fruits [27].

An image analysis technique can be applied in an on-line sorting system. It is fast, simple, convenient and non-destructive. However fruit such as mangosteen and many other kinds of fruit have a calyx, stem and various curves on the surface, so it is not easy to identify the volume from the images using calculations based on a mathematical formula for the geometric model of the volume. Therefore, this study aimed to develop a new, simplified technique of image analysis to determine the volume and subsequently to calculate the density of mangosteen.

II. Materials and Methods

A. Fruit

Mangosteens were purchased from a wholesale market in Bangkok, Thailand. Different-sized fruits were sampled (N=80) with good appearance and a maturity stage of 4-5 [28] were selected and used in this study.

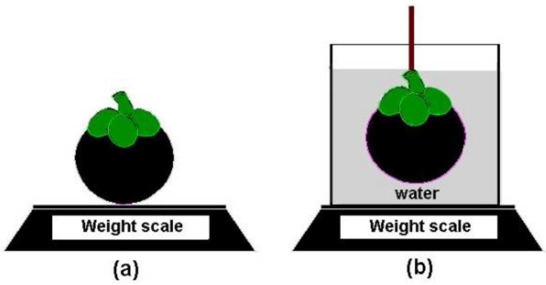

Figure 1. Sample presentation for density measurement: sample was weighed in air (a) and in water (b).

B. Density Measurement

The mass of each sample was measured using an electronic balance (Sartorius, BSA3202S-CW). The volume of each fruit was determined by the water displacement method as described by [29]. According to Archimedes' principle, the volume of an object is equal to the weight of the water displaced. As the density of water is 1.0 g/cm^3, the mass of the water displaced by the sample is equal to its volume. Thus, the volume of the displaced water was determined by mass measurement while submerging the sample in water without the sample being in contact with the sides of the container as shown in Fig. 1. Density (ρ) can be defined as the ratio of an object ́s mass (m) to its volume (V). Therefore, the sample ́s density can be calculated using equation (1):

$$\rho = \frac{m}{V} \tag{1}$$

C. Image Acquisition

Each sample was placed in a special cardboard box to control the light level when taking photographs. Pictures of each sample were captured using a digital camera (Canon; EOS 550D, Japan) as shown in Fig. 2. Due the shape of the mangosteen and calyx varying when considered from different views, six pictures of each fruit were captured when each sample was randomly oriented in a horizontal position (XY plane view) and rotated around the calyx alignment every 30^o in a clockwise direction as well taking two pictures in the vertical position (XZ plane view) at the top and bottom of the fruit. A circular piece of white cardboard with a fixed diameter (10 cm) was used as a reference plate as the background for all the pictures.

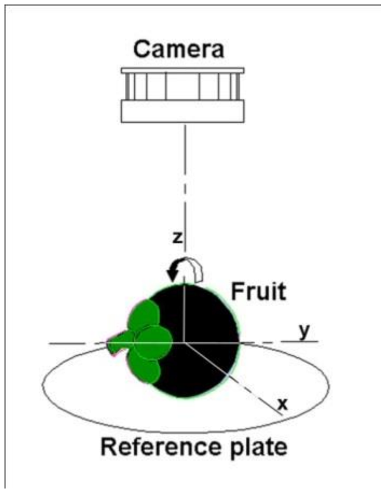

Figure 2. Schematic diagram of picture taking with digital camera

D. Image Analysis

Each picture of the sample and the reference plate was converted into a binary image. The pixels of each part in the image were then examined by the segmentation method using the image processing toolbox in the MATLAB software (MATLAB 7, The MathWorks, Inc., Natick, MA, USA). Pixels of the reference plate in each picture were used as a standard size in the image processing and were compared to those of the piece of fruit in the same picture. Pixels of the reference plate and pixels of each sample were used for volume calculation. The volume of the reference plate could be calculated as the volume of a sphere in terms of its radius (r) using equation (2):

$$Volume\ of\ sphere = \frac{4}{3}\pi r^3 \qquad (2)$$

The reference plate was analyzed using the number of pixels in the binary image. A spherical volume of the reference plate was assumed and then the radius of the reference circle in pixels was determined using equation (2).Therefore pixels could be converted to centimeters to determine the radius of the reference plate. Even though the sample was not spherical, it was assume to have the equivalent radius of a sphere. Pixels in the binary image of the sample were analyzed to calculate the volume as well as to determine subsequently the equivalent radius in pixels. The equivalent radius of the sample in pixels was converted to centimeters and then the predicted volume of the sample was calculated using equation (2).

The 2-D digital image of each picture showed only a single horizontal plane view such as the XY plane or XZ plane, but in fact, each real sample had height in the other perpendicular axis. The pixels of a picture in each horizontal layer varied according to the distance from the camera. Fig. 3 shows how the pixels of the reference plate image were determined at various heights. This information was used to define a correction factor for the calibration of the sample pixels during the image processing. The pixels of each sample image were adjusted according to the height. The height of each fruit, indicated by the boundary body line in the picture, was assumed to be at the middle of the fruit body or approximated to be the radius of each fruit (r). Therefore it was necessary to calibrate the equivalent radius of the sample using a correction factor due to the height effect. The equivalent radius in pixels was converted into the distance in centimeters. Thus, the predicted volume of the sample could be calculated using equation (2) and then the predicted density of the sample was determined using equation (1).

The predicted densities of samples from the application of the image analysis were compared with the measured densities of the samples from water displacement. The predictive accuracy was considered using the correlation coefficient (R) and the standard error of the estimate (SEE). The R computer software package (Version 3.1.2) was used for statistical analysis.

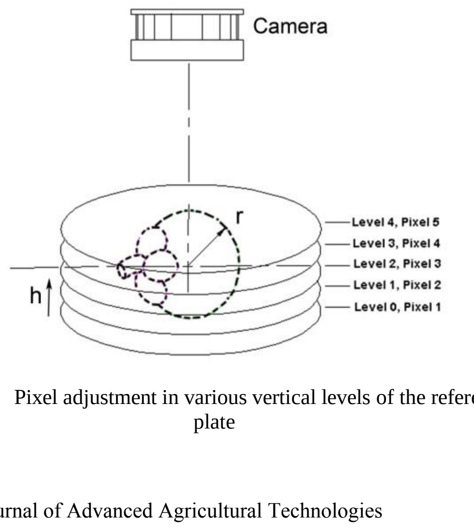

Figure 3. Pixel adjustment in various vertical levels of the reference plate

III. Results and Discussion

A. Acquisition of Mass and Density Measurement

All samples (N=80) were measured for mass and density as shown in Table I.

TABLE I CHARACTERISTICS OF MANGOSTEEN SAMPLE.

No	Mass (g)		Density from water displacement (g/cm^3)		
	Range	Averaged	Range	Averaged	SD
80	47.8-130.1	78.3	0.88-1.05	0.98	0.04

B. Density Calculation Using Image Analysis

All acquired pictures were converted from RGB images into binary images. In Fig. 4, the RGB image (Fig. 4.a) was converted into a binary image (Fig. 4.b) and a binary image of the reference plate (Fig. 4.c). The number of pixels in each part in the same picture of the reference plate and the background were calculated.

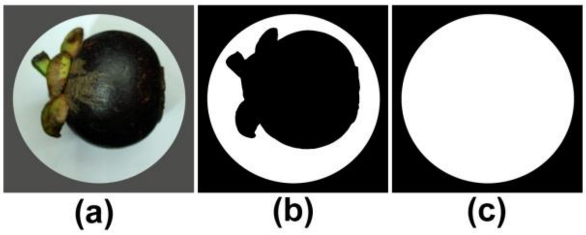

Figure 4. Image processing for mangosteen: RGB image: (a) Binary image of sample and reference plate, (b) Binary image of reference plate (c)

The sample and the reference plate in each picture were comparable. It was very important that the pixels in each part had to be individually determined and used for comparison with the reference plate only in that picture.

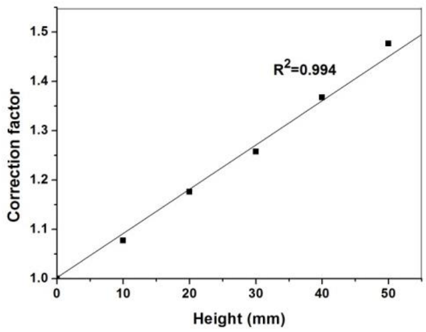

Figure 5. Relationship between correcting factor and the height

The 2-D digital image showed only a single horizontal layer but each part in the picture had to be compared using pixels. This was achieved using the effect between the 2-D image and the real objects because of the height in the perpendicular axis. For this reason, the pixels of the sample image had to be adjusted by the correction factor based on the height. The results of the test for pixel adjustment at various vertical levels of the reference plate showed that each level of the reference plate image contained different pixels. The ratio of pixel variation was calculated depending on the distance or the height (h) from the reference plate to the camera. The relationship of the ratio and the height showed a significant linear trend (Fig. 5). The linear relationship between the correcting factor and the height was determined with a high coefficient of determination (R^2= 0.994) using equation 3:

$$\text{Correction factor} = 0.901h+1 \quad (3)$$

The pixel adjustment of each sample required the acquired pixels of the sample picture from the binary image to be multiplied by the correction factor (equation 3) using the equivalent radius of the fruit for h with the height of the sample viewed in the picture being estimated to be at the mid height of the fruit.

Using the reference plate for comparison, the pixels were converted to centimeters, the equivalent radius from the six pictures in the XY plane view as well as from the two pictures in the XZ plane view (top and bottom) of the sample was averaged, and then the average volume of each sample was calculated using equation (2). The average volume of each sample was then used to determine the average density. Finally, the predicted density of each sample was determined using equation (1).

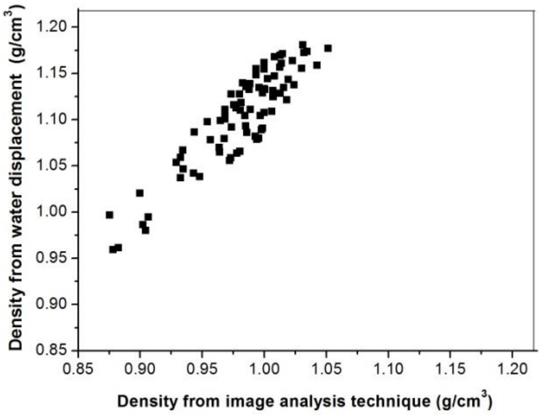

Figure 6. Scatter plot of the density from water displacement method against average density from image analysis with a prediction error

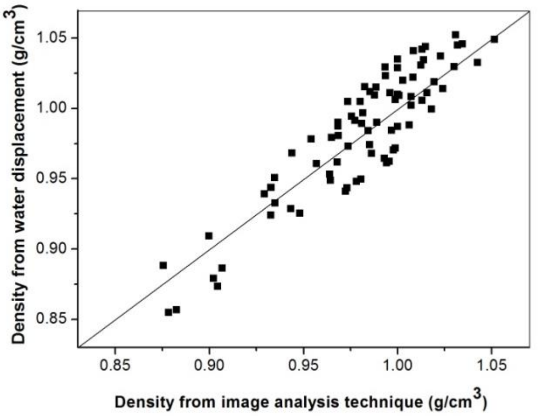

Figure 7. Scatter plot of the density from water displacement method against average density from image analysis after improvement by slope adjustment

The average density from the image analysis was compared with the density obtained using the water displacement method. The relationship showed a high correlation coefficient (R = 0.91) and a low standard error of the estimate (SEE = 0.016 g/cm^3) as shown in Fig. 6. The analysis revealed that mangosteen samples had a calyx which was void under thin sepals. This part of the calyx image was also used for volume determination. In this case, it might be possible that there was air under the sepals. Therefore, the predicted volume from the image analysis contained an error in each fruit. The results showed the over prediction of density due to the volume of the samples from the image analysis was generally larger than that of the real objects. Thus, the value of the average density from the image analysis was lower than that of the density obtained by the water displacement method. The precision of prediction can be improved by slope adjustment. In the plot shown in Fig. 7, the average density from the image analysis was divided by 1.122.

IV. Conclusion

The comparison between a reference plate and a whole fruit sample could be used to determine the fruit volume using an image analysis technique. This technique could be used for fruit having an irregular shape, calyx and stem. The predicted volume was determined using binary image analysis and then the average density was calculated. A high correlation coefficient and a low standard error of the estimate were obtained from the results of the predictive evaluation. Nevertheless, the precision of the prediction could be improved by slope adjustment of the prediction curve. The study showed that the image analysis procedure was effective for use in an on-line sorting system to evaluate the fruit quality based on the predicted density instead of the traditional floating technique. Therefore, the image analysis technique has potential to be used with fruit having various geometrical attributes and could be applied for an on-line sorting system.

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References

[1] J. A. Abbott, "Quality measurement of fruits and vegetables," *Postharvest Biology and Technology*, vol. 15, pp. 207-225, March 1999.

[2] A. M. Ramos and A. Ibarz, "Density of juice and fruit puree as a function of soluble solids content and temperature," *Journal of Food Engineering*, vol. 35, pp. 57-63, January 1998.

[3] J. H. Tsen and V. A. E. King, "Density of banana puree as a function of soluble solids concentration and temperature," *Journal of Food Engineering,* vol. 55, pp. 305-308, December 2002.

[4] T. Sugiura, H. Kuroda, D. Ito, and H. Honjo, "Correlations between specific gravity and soluble solids concentration in grape berries," *Journal of Japanese Society for Horticultural Science,* vol. 70, no. 3, pp. 380-384, 2001.

[5] R. B. Jordan, E. F. Walton, K. U. Klages, and R. J. Seelye, "Postharvest fruit density as an indicator of dry matter and ripened soluble solids of kiwifruit," *Postharvest Biology and Technology,* vol. 20, pp. 163-173, September 2000.

[6] V. A. McGlone, R. B. Jordan, R. P. Seelye, and J. Martinsen, "Comparing density and NIR methods for measurement of kiwifruit dry matter and soluble solids content," *Postharvest Biology and Technology*, vol. 26, no. 2, pp. 191-198, September 2002.

[7] V. A. McGlone, C. J. Clark, and R. B. Jordan, "Comparing density and VNIR methods for predicting quality parameters of yellow-fleshed kiwifruit (*Actinidia chinensis*)," *Postharvest Biology and Technology*, vol. 46, no. 1, pp. 1-9, October 2007.

[8] K. Kato, "Electrical density sorting and estimation of soluble solids content of watermelon," *Journal of Agricultural Engineering Research*, vol. 67, pp. 161-170, June 1997.

[9] G. P. Moreda, J. Ortiz-Cañavate, F. J. García-Ramos, and M. Ruiz-Altisent, "Non-destructive technologies for fruit and vegetable size determination – a review," *Journal of Food Engineering*, vol. 92, pp. 119-136, May 2009.

[10] M. B. Osman and A. R. Milan, *Mangosteen – Garcinia mangostana*, U.K.: Southampton Centre for Underutilised Crops, University of Southampton, 2006, p. 170.

[11] S. Teerachaichayut, K. Y. Kil, A. Terdwongworakul, W. Thanapase, and Y. Nakanishi, "Non-destructive prediction of translucent flesh disorder in intact mangosteen by short wavelenght near infrared spectroscopy," *Postharvest Biology and Technology*, vol. 43, pp. 202-206, February 2007.

[12] C. Corrado, F. Antonucci, F. Pallottino, J. Aguzzi, D. W. Sun, and P. Menesatti, "Shape Analysis of agricultural products: A Review of recent research advances and potential application to computer vision," *Food Bioprocess Technology*, vol. 4, pp. 673-692, July 2011.

[13] F. Lopez-Garcia, G. Andreu-Garcia, J. Blasco, N. Aleixos, and J. Valiente, "Automatic detection of skin defects in citrus fruits using a multivariate image analysis approach," *Computers and Electronics in Agriculture*, vol. 71, pp. 189–197, February 2010.

[14] F. Mendoza, R. Lu, D. Ariana, H. Cen, and B. Bailey, "Integrated spectral and image analysis of hyperspectral scattering data for prediction of apple fruit firmness and soluble solids content," *Postharvest Biology and Technology*, vol. 62, pp. 149–160, May 2011.

[15] G. A. Leiva-Valenzuela, R. Lu, and J. M. Aguilera, "Assessment of internal quality of blueberries using hyperspectral transmittance and reflectance images with whole spectra or selected wavelengths," *Innovative Food Science and Emerging Technologies*, vol. 24, pp. 2–13, March 2014.

[16] H. Zheng, B. Jiang, and H. Lu, "An adaptive neural-fuzzy inference system (ANFIS) for detection of bruises on Chinese bayberry (*Myrica rubra*) based on fractal dimension and RGB intensity color," *Journal of Food Engineering*, vol. 104, pp. 663–667, Feb. 2011.

[17] L. Qiang, and T. Mingjie, "Detection of hidden bruise on kiwi fruit using hyperspectral imaging and parallelepiped classification," *Procedia Environmental Sciences*, vol. 12, pp. 1172 – 1179, 2012.

[18] M. A. Teena, A. Manickavasagan, L. Ravikanth, and D. S. Jayas, "Near infrared (NIR) hyperspectral imaging to classify fungal infected date fruits," *Journal of Stored Products Research*, vol. 59, pp. 306-313, October 2014.

[19] R. P. Haff, S. Saranwong, W. Thanapase, A. Janhiran, S. Kasemsumran, and S. Kawano, "Automatic image analysis and spot classification for detection of fruitfly infestation in hyperspectral images of mangoes," *Postharvest Biology and Technology*, vol. 86, pp. 23–28, June 2013.

[20] S. Ercisli, B. Sayinci, M. Kara, C. Yildiz, and I. Ozturk, "Determination of size and shape features of walnut (*Juglans regia* L.) cultivars using image processing," *Scientia Horticulturae*, vol. 133, pp. 47–55, 2012.

[21] S. Cubero, M. P. Diago, J. Blasco, J. Tardaguila, B. Millan, and N. Aleixos, "A new method for pedicel/peduncle detection and size assessment of grapevine berries and other fruits by image analysis," *Biosystems Engineering*, vol. 117, pp. 62-72, 2014.

[22] V. Mohammadi, K. Kheiralipour, and M. Ghasemi-Varnamkhasti, "Detecting maturity of persimmon fruit based on image processingtechnique," *Scientia Horticulturae*, vol. 184, pp. 123–128, 2015.

[23] M. Ngouajio, W. Kirk, and R. Goldy, "A simple model for rapid and nondestructive estimation of bell pepper fruit volume," *HortScience*, vol. 38, no. 4, pp. 509-511, July 2003.

[24] A. Koc, "Determination of watermelon volume using ellipsoid approximation and image processing," *Postharvest Biology and Technology*, vol. 45, pp. 366-371, September 2007.

[25] C. K. Walker and J. F. Panozzo, "Measuring volume and density of a barley grain using ellipsoid approximation from a 2-D digital image," *Journal of Cereal Science*, vol. 55, pp. 61-68, January 2012.

[26] M. Rashidi and G. Mohammad, "Determination of kiwifruit volume using ellipsoid aproximation and image-processing methods," *International Journal of Agriculture & Biology*, vol. 10, pp. 375-380, 2008.

[27] M. Omid, M. Khojastehnazhand, and A. Tabatabaeefar, "Estimating volume and mass of citrus fruits by image processing technique," *Journal of Food Engineering*, vol. 100, pp. 315–321, April 2010.

[28] Y. Palapol, S. Ketsa, D. Stevenson, J. M. Cooney, A. C. Allan, and I. B. Ferguson, "Colour development and quality of mangosteen (*Garcinia mangostana* L.) fruit during ripening and after harvest," *Postharvest Biology and Technology*, vol. 51, pp. 349-353, March 2009.

[29] N. N. Mohsenin, *Physical Properties of Plant and Animal Materials*, New York: Gordon and Breach Science Publishers, 1986, pp. 841.

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S. Teerachaichayut, A. Terdwongworakul, J. Phonudom, and W. Uamsatianporn, "The robustness of PLS models for soluble solids content of mangosteen using near infrared reflectance spectroscopy," *Global Science Books, Fresh Produce*, vol. 3, no. 1, pp. 60–63, May 2009.

S. Teerachaichayut, A. Terdwongworakul, W. Thanapase, and K. Kiji, "Non-destructive prediction of hardening pericarp disorder in intact mangosteen by near infrared transmittance spectroscopy," *Journal of Food Engineering*, vol. 106, no. 3, pp. 206–211, October 2011.

S. Teerachaichayut, S. Suktanarak, and S. Kasemsumran, "Non-destructive detection of internal mold infection in sweet tamarind using short wavelength near infrared sectroscoy," *Acta Horticulturae (ISHS)*, vol. 1053, pp. 113-119, October 2014.

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A. Puangsombut, S. Pathaveerat, A. Terdwongworakul, and K. Puangsombut, "Evaluation of internal quality of fresh-cut pomelo using Vis/NIR transmittance," *Journal of Texture Studies*, vol. 43, no. 6, pp. 445-452, 2012.

A. Terdwongworakul, N. Nakawajana, S. Teerachaichayut, and A. Janhiran, "Determination of translucent content in mangosteen by means of near infrared transmittance," *Journal of Food Engineering*, vol. 109, no. 1, pp. 114-119, 2012.

P. Timkhum and A. Terdwongworakul, "Non-destructive classification of durian maturity of 'monthong' cultivar by means of visible spectroscopy of the spine," *Journal of Food Engineering*, vol. 112, no. 4, pp. 263-267, 2012.

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P. Jannok, S. Ratree, K. Uchida, and S. Kawano, "Development of a universal NIR calibration model for determining the Brix value of intact apple, pear and persimmon fruits," in *Proc. 3rd Asian Near-Infrared Symposium (ANS2012)*, Thailand, 2012, pp. 14-18.

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