วิศวกรรมสาร มข. ปีที่ 33 ฉบับที่ 5 (555 - 563) กันยายน - ตุลาคม 2549 บทความวิจัย
KKU Engineering Journal Vol. 33 No .5 (555 – 563) September – October 2006

การวัดความสุกแก่ทุเรียนพันธุ์หมอนทองแบบไม่ทำลายด้วยความแข็งแรงก้านผลและความถี่เสียง*

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บทคัดย่อ

บทความวิจัยนี้ศึกษาการวัดความแก่ของทุเรียนพันธุ์หมอนทองแบบไม่ทำลาย โดยนำผลทุเรียน 130 ผล ใน 7 ช่วงอายุหลังดอกบานตั้งแต่ 105 วัน จนถึง 136 วัน ตั้งแต่อ่อนจนแก่ มาวัดความแข็งแรงก้านด้วยเครื่องมือบีบก้านที่สร้างขึ้นโดยเฉพาะ โดยบันทึกแรงกดตามแนวรัศมีกับระยะกด และวัดเสียงเคาะเพื่อนำมาหาความถี่ธรรมชาติ เนื้อทุเรียนถูกนำมาอบแห้งเพื่อหาเปอร์เซ็นต์น้ำหนักเนื้อแห้งสำหรับใช้เป็นดัชนีอ้างอิงความแก่ของทุเรียน การวิเคราะห์สถิติเพื่อศึกษาความสัมพันธ์พบว่า สำหรับพารามิเตอร์ที่เกี่ยวข้องกับความแข็งแรงก้านนั้น พื้นที่ใต้กราฟแรงกดกับระยะกด มีความสัมพันธ์ทางบวกกับเปอร์เซ็นต์น้ำหนักเนื้อแห้งโดยมีสัมประสิทธิ์สหสัมพันธ์ r = 0.808 และความถี่ธรรมชาติเสียงเคาะมีความสัมพันธ์ทางลบกับเปอร์เซ็นต์น้ำหนักเนื้อแห้งที่ r = -0.448 และจากการวิเคราะห์ถดถอยพหุคูณพบว่า พื้นที่ใต้กราฟแรงกดกับระยะกดและความถี่ธรรมชาติมีความสัมพันธ์เชิงเส้นกับเปอร์เซ็นต์น้ำหนักเนื้อแห้งที่ r = 0.844 และสัมประสิทธิ์ถดถอยพหุคูณ R^2 = 0.713

คำสำคัญ : ความสุกแก่ทุเรียน ความแข็งแรงก้าน ความถี่ธรรมชาติ

* รับต้นฉบับเมื่อวันที่ 22 พฤษภาคม 2549 และได้รับบทความฉบับแก้ไขเมื่อวันที่ 3 สิงหาคม 2549

Non-destructive Maturity Measurement of “Montong” Durian Using Stem Strength and Resonant Frequency*

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ABSTRACT

This research studied a non-destructive measurement of maturity of “Montong” durian. Durians, 130 fruits, were harvested in 7 stages of maturity starting from 105 days to 136 days after blossom. The samples were taken for non-destructive measurements of the stem strength using the uniquely built device and force-deformation responses to radial compression were recorded. The sound of fruit tapping was also acquired for resonant frequency determination. The pulp of the samples was later oven dried for determination of the dry matter percentage that was used as maturity reference. The statistical correlation analysis of various stem strength related parameters showed that the area under the force-deformation curve was positively correlated the most with the dry matter percentage at correlation coefficient r = 0.808. The negative relationship was found for the resonant frequency and the dry matter percentage with r = -0.448. The multiple linear regression analysis indicated that the area under the force-deformation curve and the resonant frequency could be used in linear combination for the best prediction with multiple coefficient of correlation (r) = 0.844 and multiple coefficient of determination (R^2) = 0.713.

Keywords : Durian Maturity, Stem Strength, Resonant Frequency

* Original manucript submitted: May 22, 2006 and Final manucript received: August 3, 2006

Introduction

Thailand is one of leading durian exporters. The most serious problem facing the exporters has been the quality control of the exported durians. Maturity is the quality that is the most important index in marketing. Every year there are some immature durians left mixing with mature durians, as they are all exported. One of the reasons is that highly skilled workers are needed for checking the maturity of durian. Very often there is a shortage of such skilled workers around at the short period of exporting time. The inclusion of immature durians usually leads to lower price and especially tarnishes the image of the particular exporter and durian exporting industry as a whole.

Kosiyachinda (1995) compiled various indices the farmers use to detect the maturity. They are for example days after blossom, the stem strength, the generated sound when tapping the durian, resistance to the tip bending of two adjacent thorns, color of the thorn tip and so on. However judging the maturity of the durians by using these indices necessitates long experiences and expertise of the judging worker and most importantly they are all subjective methods. Recently there have been a number of researches investigating on objective means for non-destructive measurement of maturity of the durians. The impulse response technique as reported by Kouno *et al.* (1993) was employed for following the change in resonant frequency of durians of "Montong" cultivar while developing on trees (Terdwongworakul *et al.*, 1997 and Terdwongworakul *et al.*, 1998). The same durian fruits were kept developing on trees while they were tapped every week. The volume of each fruit was also measured by means of water replacement following which the weight (m) was determined by multiplication of the density of harvested durians of the same maturity. The resonant frequency of the sound signal was extracted by means of Fast Fourier Transform (FFT). It was shown that the frequency index, $f^2\ln(m^{2/3})$, monotonously reduced with maturity. The results were consistent for both in 1997 and in 1998. An investigation was also made to establish the fundamental relationship between maximum frequency responses (MFR) on Montong durians and the storage day (Sombatwong *et al.*, 2003). Durians were stored for 4 days and every day each fruit was knocked and its sound was recorded for subsequent Fourier transform to obtain the maximum frequency response. The results showed that the MFR was inversely proportional to the number of storage day. In another research, X-ray CT images of durians were produced to examine the thickness of the husk and the color of the flesh as both were related to the quality of the durians (Yantarasri *et al.*, 1996). The obtained images could reveal the internal damage caused by the insects. The conclusion was that the X-ray CT was capable of separating durians into immature, mature and overripe durians. Kongratanaprasert (2000) attempted to implement the ultrasonic technique to monitor the maturity of durians. The time related ultrasonic signals were analyzed based on a combination of wavelet and Fast Fourier Transform that resulted in relatively high accuracy of prediction of maturity.

The harvesters usually judge the durian maturity by considering various parameters in combination before making the decision. The stem and the response sound when tapping durian are those of the parameters the harvesters considered. This research proposed the nondestructive means of measuring the stem strength and acoustic response in combination in an attempt to obtain the useful index for maturity prediction of durians.

Materials and methods

Montong durians in an orchard in Chantaburi province were tagged when blossom for tracking days after blossom. Once a week about 20 durians were harvested and the measurements for the stem strength and the acoustic response were taken. The measurements started approximately three weeks before harvest age (about 120 days after blossom) and ended three weeks after the harvest age, accounting for seven measurements totally. The stem strength was represented by various parameters to be derived from data in graphs (Figure 1) showing relationship between a compression force (F) and the stem deformation (D) or F/D curve. F/D curve was obtained by using a stem-compressing device uniquely designed as shown in Figure 2. Each durian fruit was placed with its stem horizontal between two metal plates of the device at which the stem was compressed radially. The force was exerted by means of stepping motor and was transduced through the strain gage circuit. Simultaneously the traverse deformation of the stem up to 3 mm was recorded by counting the number of turns the stepping motor rotated.

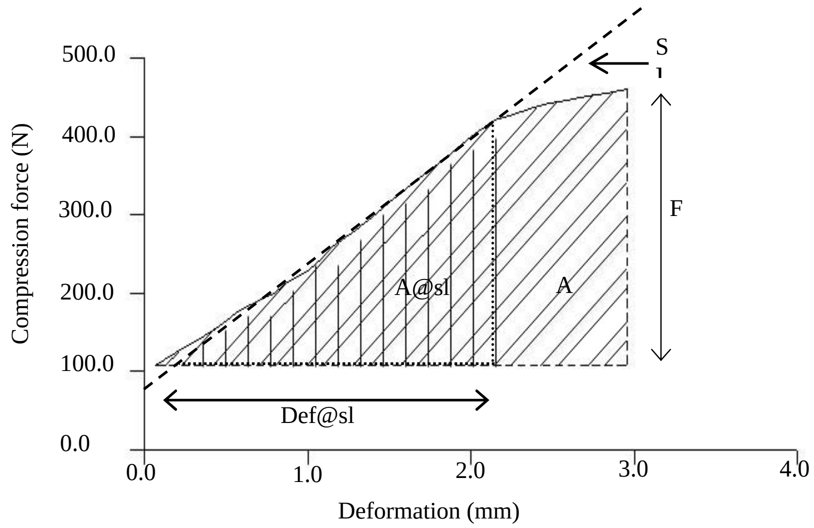

Figure 1 *Change in the force against the deformation on radially compressing the durian stem.*

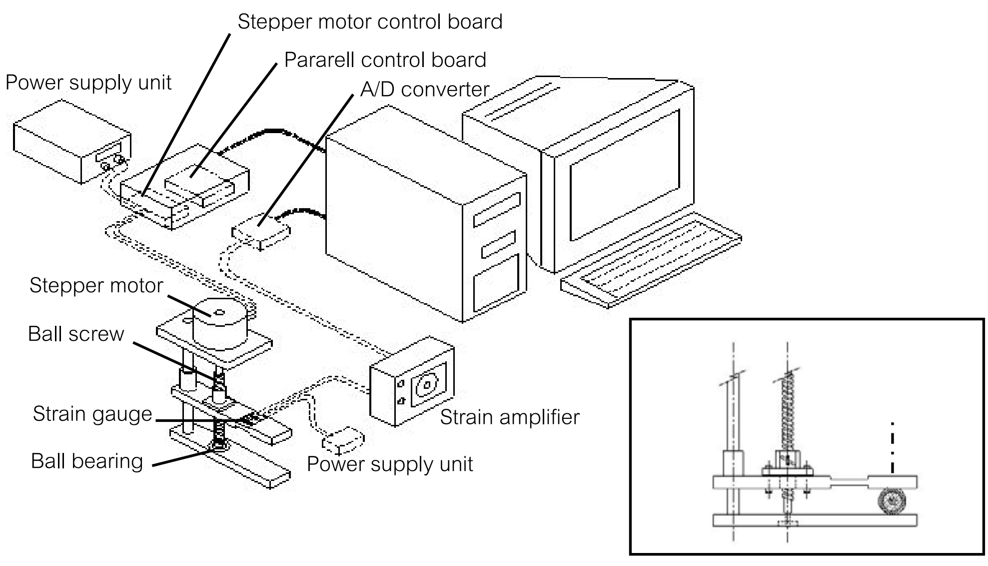

Figure 2 *The stem compressing device used for determination of the stem strength showing the durian stem placed in measured position in the inset.*

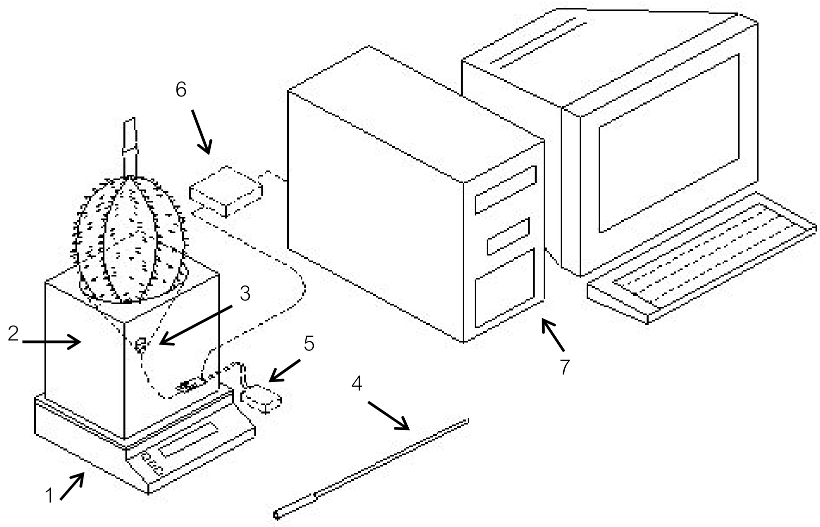

Figure 3 *The device used for measuring the sound when tapping the durian consisting of 1) the digital scale 2) a supporting box 3) a microphone 4) a tapping stick 5) a battery 6) an amplifier and 7) the processing computer.*

Figure 3 depicts the measurement using a microphone of the acoustic sound when tapping the durian placed with the stem in an upright position. The analog sound signal was digitally converted by A/D converter installed in the computer and the durian weight was sent to the computer through RS232 cable from the digital scale. Following both the stem strength and the acoustic response measurements, each durian was cut open and the flesh was oven dried until there was no change in weight. The percentages of flesh dry weight was then calculated and used as a maturity reference (Sangwanangkul, 1998).

Some interesting parameters of the stem strength were derived from Figure 1 and used for further analyses. They were exemplified by a maximum force (F), area under the F/D curve (A), elastic modulus (E), a deformation at maximum slope (Def@sl), and ratio of deformation at the maximum slope to the stem diameter (Def@sl/Di). As for the parameters associated with the acoustic response, the resonant frequency (RF) and resonant frequency index ($RF^2m^{2/3}$ where m is the durian mass) were used.

Multiple regression analyses were performed to get the best correlation between those nondestructive parameters against the percentage of flesh dry weight.

Results and discussion

The stem strength parameter

Following the regression analysis between each stem strength related parameters and the flesh dry weight (Table 1), it was found that parameter A was best correlated to the flesh dry weight with r = 0.808. The area under the curve between the compression force and the corresponding radial deformation (A) increased with an increase in the flesh dry weight as illustrated in Figure 4. The area in this case represented the toughness or the energy that the stem could absorb before breaking. It implied that as durians were getting mature with their flesh dry weight increasing, their stems were getting tougher to break.

	% Dry weight	F (N)	E (MPa)	sl (N/mm)	Def@sl (mm)	A (N.mm)	A@sl (N.mm)	Def@sl/Di
% Dry weight	1.000	0.728**	0.723**	0.403**	-0.372**	0.808**	-0.253**	-0.412**
F (N)	0.728**	1.000	0.979**	0.620**	-0.137	0.888**	0.003	-0.267**
E (MPa)	0.723**	0.979**	1.000	0.611**	-0.172	0.869**	-0.038	-0.328**
sl (N/mm)	0.403**	0.620**	0.611**	1.000	0.087	0.525**	0.184*	-0.057
Def@sl (mm)	-0.372**	-0.137	-0.172	0.087	1.000	-0.380**	0.971**	0.701**
A (N.mm)	0.808**	0.888**	0.896**	0.525**	-0.380**	1.000	-0.227**	-0.504**
A@sl (N.mm)	-0.253**	0.003	-0.038	0.184*	0.971**	-0.227**	1.000	0.635**
Def@sl/Di	-0.412**	-0.267**	-0.328**	-0.057	0.701**	-0.504**	0.635**	1.000

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed)

Table 1 *Regression analyses showing correlation coefficients between each parameter related to the stem strength and percentage of flesh dry weight*

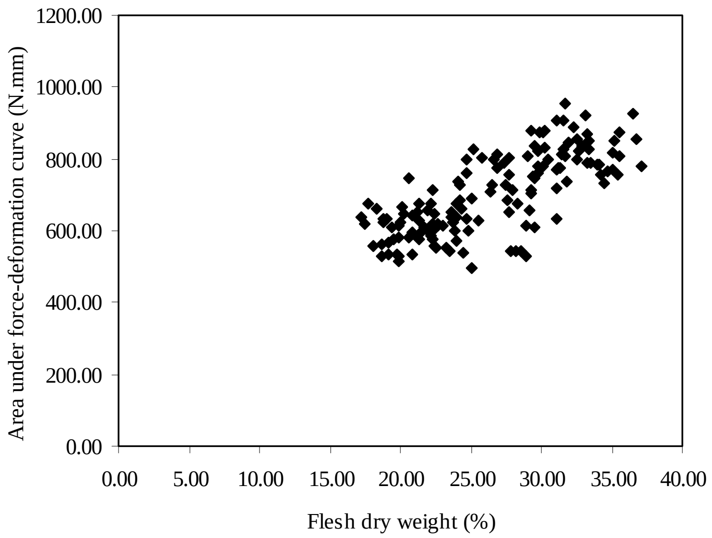

Figure 4 *Illustration of a change in area (N.mm) under the F/D curve against flesh dry weight (%) (Matured durian has equal or grater than 32% flesh dry weight.) (ACFS, 2003)*

The acoustic response parameter

Figure 5 demonstrates that the resonant frequency of durians was lower as they gained more flesh dry weight or were more mature. The coefficient of correlation, r was –0.448 for such an inverse relationship. The resultant decrease in the resonant frequency agreed with previous research (Terdwongworakul *et al.*, 1997) in which the lower pitch of the sound was generated when knocking durians with greater maturity.

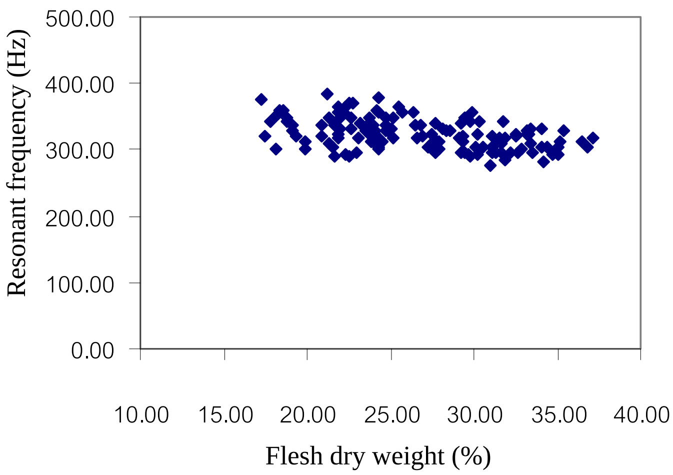

Figure 5 *The relationship between the resonant frequency of the tapping sound and the flesh dry weight (%).*

Combination of the stem strength and the acoustic response parameters

All parameters relating to both the stem strength and the acoustic response were combined either linearly or nonlinearly and analyzed by the multiple regression technique to get the best predicting model for the flesh dry weight. Inspection of the coefficient of correlation and standard error of estimate (SEE) revealed that the best correlation was resulted from the linear model in which the area under the F/D curve and the resonant frequency were included. An addition of the resonant frequency to the area as predictors improved the predictability for the flesh dry weight with an increase in r to 0.844 and lower SEE = 2.737 (prediction error for the calibration set). Such a linear model is given as follows:

$$\%Dm = 20.663 + 0.182A - 0.0562RF$$

where %Dm is the percentage of flesh dry weight
A is the area under the F/D curve and
RF is the resonant frequency of durian.

The contribution of the area to the prediction of the flesh dry weight was greater than that of the resonant frequency as quantitatively indicated by the coefficients of the given terms. Correlation of the area under the F/D curve and the resonant frequency to the destructive measurement of flesh dry weight were deemed to be sufficiently high for fairly good prediction of durian maturity. Correlation coefficients of greater than 0.80 are generally accepted as high enough for prediction (Abbott and Massie, 1995).

The model was used as the maturity index to predict the flesh dry weight of 15 durian fruits in the following season. The result was shown in Figure 6 with standard error of prediction, SEP = 4.550. The accuracy of prediction was lower which could be attributed to different season.

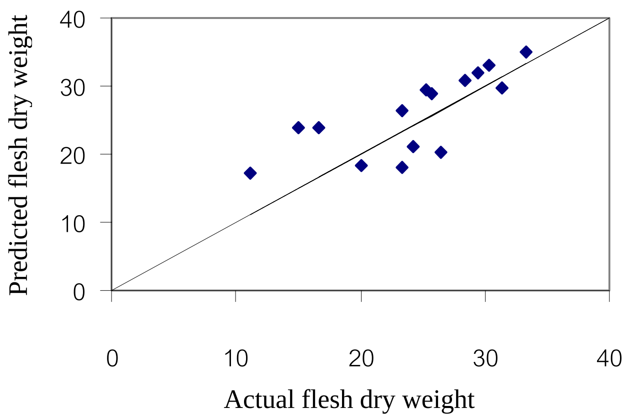

Figure 6 *Scatter plot for prediction of flesh dry weight using the linear model based on the stem strength (A) and the acoustic response (RF).*

The model linearly combining the area as the stem strength representative and the resonant frequency as the acoustic response parameter reflected to some extent the practices that the harvesters use for picking the mature durians. Actually the harvesters process a lot of information subjectively prior to making the decision. Nevertheless the stem and the sound when tapping the fruit are just a few of the useful information.

Conclusions

The durian maturity could be better predicted using more than one parameter. The model combining the stem strength parameter (A) and the acoustic response (RF) could predict the flesh dry weight better than the models with one parameter. The obtained linear model was best used to describe the variation of the flesh dry weight by 71.3% (r^2 = 0.713). The correlation parameters for each model were compared as follows:

1. r=0.808 for the area under the F/D curve as a predictor,
2. r=0.448 for the resonant frequency as a predictor and
3. r=0.844 for both the area and the resonant frequency as predictors.

The stem strength and the acoustic response had advantage over some parameters in such that they could be measured objectively by simple devices. However further research is needed to determine other parameters that the harvesters use subjectively for judging the maturity but can be measured nondestructively.

Acknowledgements

Thanks are due to the development program of the graduate study and research on postharvest technology, Kasetsart university for the research funding. The preparation of this paper could not be done without the computer facility provided by pre-special research unit under the research center of irrigation, agricultural and food engineering, faculty of engineering at Kamphaengsaen, Kasetsart University.

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