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A Simple and Inexpensive Technique for Estimating Leaf Surface Area of Muskmelon (*Cucumis melo* L.) [1]

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Abstract

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Leaf area is a valuable index in identifying muskmelon (*Cucumis melo* L.) growth and development. A simple technique was developed for estimating leaf surface area (A) of muskmelon with measurements of leaf length from the sinus base to the apex of leaf along midrib (L) and/or maximum leaf width (W) without the use of any expensive instruments. Leaves for three muskmelon varieties, Chioumih, Zhufen and Tianhun were collected from different levels of the canopy of plants during the growing season in 2007 at Taiwan Agricultural Research Institute, Wufeng, Taichung, Taiwan. Each leaf was measured for L, W and A. Data analysis were performed by regression technique. Results showed that differences in leaf shape among these varieties affected the performances of prediction accuracy in different models for leaf area estimation. The linear equations having W^2 as the independent variable provided the most accurate estimation of A for Chioumih and Zhufen muskmelons, with leaf area coefficients of 0.70 and 0.62, respectively. For Tianhun muskmelon, the equation of $A = 0.67 \times L \times W$ exhibited the highest accuracy of leaf area estimation, and the equations of $A = 0.62 \times L^2$ and $A = 0.71 \times W^2$ could also be adopted. With these models, a high degree of 1:1 relationship was obtained between measured and predicted leaf areas, and they produced satisfactory results of lower mean squared deviation (in the range of 451 to 762), lower percentage of deviation for total leaf area (≦1.34%), and lower mean percentage of deviation for individual leaf area (≦0.25%). The linear regression model was simple, rapid, inexpensive and accurate for estimation of leaf surface area of muskmelon and nondestructive to plant growth.

Key words: Surface leaf area, Nondestructive estimation, Linear regression model, Leaf shape, Prediction accuracy.

Introduction

Muskmelon (*Cucumis melo* L.) is an important specialty fruit crop in Taiwan. It is a species of melon that has been developed into many cultivated varieties. The common varieties grown in Taiwan are Chioumih, Zhufen and Tianhun, which are noted for their sweet, juicy, musky-scented and strongly netted-rind. Chioumih muskmelon is an early mature variety, 10–15 days earlier than Zhufen and Tianhun. The fruit of Chioumih is

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oval-shape with light-yellow skin and honey-white flesh, whereas the fruit of Zhufen and Tianhun are round-shape with green skin and orange flesh. In Taiwan, muskmelon plants are grown in nethouse or in simple-structured greenhouse rather than in open fields in order to ensure production of high-quality marketable fruits.

Leaf area is a valuable index in identifying growth, photosynthesis, transpiration, light interception, and energy balance of muskmelon (Cohen *et al*. 1999; Russo *et al*. 2002; Shih 2002). Like other crops, measuring the surface area of a large number of muskmelon leaves can be time consuming. Detached leaf methods such as tracing, blueprinting, photographing, or using a conventional planimeter, have been used for measurement of surface area of leaves but these techniques are harmful to plants. Thus, nondestructive leaf area measurement methods are more desirable because continual use of the same plants over time can reduce the variability of the experiments, compared to the destructive sampling methods using detached leaves. Leaf surface area of watermelon (*Cucumis melo* L.) plants can be measured accurately and nondestructively by using digital photos with image measurement software (Lopes *et al*. 2007), but the processing procedure is time consuming, and the image analyzing facilities are expensive and unaffordable, especially in developing countries. Therefore, developing an inexpensive, rapid, reliable and nondestructive method for measuring leaf surface area of muskmelon is paramount to horticulturists.

The use of equations that require measurement of leaf dimensions, length (L) and/or width (W), as input for predicting the leaf surface area eliminates the need for expensive equipments such as image analyzer or leaf area meters. These methods have been used in numerous horticultural plants (Robbins & Pharr 1987; Chirinos *et al*. 1997; Montero *et al*. 2000; Nascimento *et al*. 2002; Lu *et al*. 2004; Blanco & Folegatti 2005; Cittadini & Peri 2006; Rouphael *et al*. 2006; Cristofori *et al*. 2007; Peksen 2007; Rouphael *et al*. 2007). Chirinos *et al*. (1997) reported that the individual leaf area of field grown 'Durango' hybrid melon (*Cucumis melo* L.) could be estimated by the logarithmic form of the gamma equation of $\ln A = a + bW + c\ln W$, or by the quadratic equations of $A = a + bW + cW^2$ or $A = a + bW^2$ (where A is leaf area per leaf, W is maximum leaf width, ln is natural logarithmic transformation, and a, b, c are constants). Nascimento *et al*. (2002) pointed out that the leaf area of Gold Mine melon (*Cucumis melo* L.) could be estimated from the exponential equation of $A = aW^b$. However, these models with more than one constant are too complicated for horticulturists. We need a simple equation for nondestructive leaf surface area estimation in muskmelon. In addition, leaf length alone can be used to estimate the area of nonexpanded leaves as it is very difficult to measure width of such leaves (Lu *et al*. 2004). The equation of a constant × leaf width × leaf length has been successfully used for estimation of leaf area in many crops (Robbins & Pharr 1987; Montero *et al*. 2000; Ogoke *et al*. 2003; Lu *et al*. 2004; Blanco & Folegatti 2005; Cittadini & Peri 2006; Rouphael *et al*. 2006; Cristofori *et al*. 2007; Peksen 2007). The objectives of this study were to develop a simple, accurate, nondestructive and time-saving model for leaf area estimation in muskmelon, and to analyze variations of leaf area coefficients among three tested varieties.

Materials and Methods

Data acquisition

Three muskmelon varieties, Chioumih, Zhufen and Tianhun were used in this study. The experiments were conducted in a nethouse at the Taiwan Agricultural Research Institute (TARI), Wufeng, Taichung, Taiwan. Sterilized seeds were sowed in 72-cell soil plugs on 29 Jan. 2007 and seedlings were transplanted into 80-L (95 cm × 60 cm × 17.5 cm) nourishing substrates in soil bags (Klasmann potgrond H; Klasmann-Deilmann GmbH, Geeste-Groß Hesepe, Germany) at 30 days after sowing. Each variety was planted in 16 bags, two plants per bag at 40 cm apart. The planting bags were placed in a randomized complete block design with 4 replications. The row spacing was 15 cm. Each bag received 5 g of 15-15-15-4 (N-P_2O_5-K_2O-MgO) compound fertilizer every 10 days within 1 month after transplanting and again 10 g of the same compound fertilizer every 15 days thereafter until harvest. Irrigation was scheduled only once every 5–7 days for young plants, requiring an estimated 1.5 L per bag. After fruit starting to expand, the plants were watered every 3 days, requiring an estimated 2 L per bag. Plants were kept free from weeds, insects, and diseases by proper culture managements.

For each muskmelon variety, a total of 100 leaves varied in size from large to small were selected randomly and removed from different levels of the canopy of plants during the growth period before harvest. After removal, surface area of each leaf (A) was measured immediately using an area meter (LI-3100; LICOR, Lincoln, NE, USA) calibrated to $0.01 cm^2$. In addition, length from the sinus base to the apex of leaf along midrib (L) and maximum width (W) of each leaf were measured to the nearest 0.1 cm. The quantity descriptors of a muskmelon leaf for the varieties, Chioumih, Zhufen and Tianhun, were shown in Fig. 1. The leaf shapes of these varieties were somewhat different. Leaves of Tianhun muskmelon were heart-shape with two rounded lobes, while leaves of Chioumih and Zhufen muskmelon were kidney-shape with four to eight lobes. Lobe depth also varied with variety,

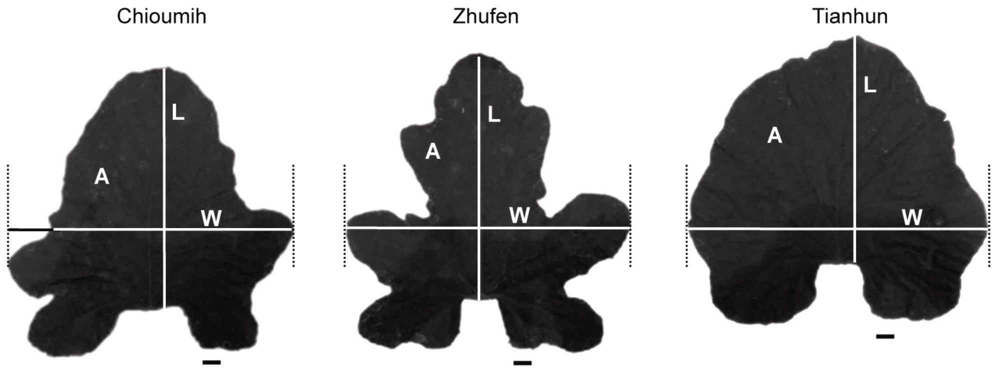

Fig. 1. Diagram of a muskmelon leaf showing positions of quantity descriptors for the varieties, Chioumih, Zhufen and Tianhun. (A, leaf area; L, leaf length from the sinus base to the apex of leaf along midrib; W, maximum leaf width).

harsh textured leaves for Zhufen and soft textured leaves for Chioumih and Tianhun. For all varieties, the leaf sinus and the point of petiole attachment were coincident. The tips of the smooth arcs of leaf lobes were generally difficultly determined for the three muskmelon varieties, which resulted in high variations of the measurement of maximum leaf length. Therefore, maximum leaf length as a dimension factor in predicting the area of muskmelon leaves was not used in this study. In addition, measurement of leaf length from the sinus base to the apex of leaf along midrib is easier than the maximum leaf length because it could be measured directly by connecting two well-defined points. The W was measured from end-to-end between the widest lobes of the leaf perpendicularly to the midrib.

Model calibration and validation

This study examined the relationship between A and L and/or W dimensions in an attempt to identify appropriate equations for use in models for the estimation of leaf surface area of muskmelon. The data of the total observations from each variety was randomly split into two halves. The first half was used to calibrate the model, and the other half was used for validation. Linear regression equations passing through the origin were fitted and evaluated for each variety using alternatively the length, the width and their product as independent variables from the calibration data. Mean squared error (MSE) and the values of regression coefficients (K) were estimated and the final equation was selected based on the combination of the highest coefficient of determination (R^2) and lowest MSE. The validation data were used to compare the leaf area predicted from different models against measured leaf area for each variety. Data of measured area (Am) and predicted area (Ap) per leaf were used to fit a linear equation. The slopes were tested to see if they were significantly different from the slope of the 1:1 correspondence line (Dent & Blackie 1979). The statistics, mean squared deviation (MSD), percentage of deviation for total area (D), and mean percentage of deviation for individual leaf area (MD) were also calculated on total leaf area basis and used to quantify the model measurement discrepancy (Whisler *et al*. 1986; Lu *et al*. 2004):

$$\mathrm{MSD} = \sum_{i=1}^{n} (\mathrm{Am_i} - \mathrm{Ap_i})^2 / n$$

$$\mathrm{D} = \left| \sum_{i=1}^{n} \mathrm{Am_i} - \sum_{i=1}^{n} \mathrm{Ap_i} \right| / \sum_{i=1}^{n} \mathrm{Am_i} \times 100$$

$$\mathrm{MD} = \left(\sum_{i=1}^{n} \left| \mathrm{Am_i} - \mathrm{Ap_i} \right| / \sum_{i=1}^{n} \mathrm{Am_i} \right) / n \times 100$$

where n is the number of leaves included in calculation. All the statistical analyses were conducted using PC Version 9.1 of the Statistical Analyses System for Windows (SAS Institute Inc. 2004).

Results and Discussion

The leaf area coefficients K in different regression models were estimated by the calibration data for each of the three varieties of muskmelon. All of the regressions were highly significant ($P < 0.01$), and all of the R^2 exceeded 0.97 (Table 1). Based on the selection criteria of highest R^2 and lowest MSE, the equations of $A = K \times W^2$ provided the most accurate estimation of surface area per leaf for Chioumih and Zhufen muskmelons, with K values of 0.70 and 0.62, respectively. The length-width model had slightly higher MSE values than the width model, but doubled the time required for leaf measurement. Therefore, the model involved one variable was preferable because of its simplicity and convenience. As stated by Robbins & Pharr (1987), model selection requires a balance between predictive qualities of the model and the economy of including the least number of variables necessary to predict A. For Chioumih and Zhufen muskmelons, the models with only leaf length were less acceptable for estimating A, due to their higher MSE values. On the other hand, for Tianhun muskmelon, the length and length-width models showed lower MSE values than the width model. A best fit was achieved using A = 0.67 × L × W than using other equations. The equation of $A = 0.62 \times L^2$ could be adopted, because it required one measurement per leaf. Length from the sinus base to the apex of leaf along midrib was generally easier to measure than maximum leaf width because it did not need to consider the line perpendicular to the leaf length. In addition, leaf length alone can be used to estimate the area of nonexpanded leaves as it is very difficult to measure width of such leaves. The width model of $A = 0.71 \times W^2$ for Tianhun muskmelon might be an alternative for the purpose of finding a consistent form of equation across varieties.

Comparisons between measured and predicted leaf area from the validation data using three models for Chioumih and Zhufen showed all good fits ($R^2 > 0.98$) in regression analysis, but only the width models were not significantly different from the 1:1 line ($P > 0.05$) (Fig. 2). Moreover, the predicted areas from width models were very close to the measured areas (Table 2). From the test results of prediction accuracy, the width models for Chioumih and Zhufen muskmelons provided more accurate estimates of leaf area than the other models, giving lower values of MSD (632 and 608, respectively), D (≦ 1.34%) and MD (≦ 0.18%). The length and length-width models for Chioumih and Zhufen showed a significant underestimation of 4.1–7.7% in predicting leaf area (Fig. 2). There were very close relationships between measured and predicted leaf area in all three models for Tianhun muskmelon (Fig. 2), producing satisfactory results of lower values of MSD (in the range of 451 to 762), D (between 0.26 and 0.67%) and MD (≦ 0.25%) (Table 2). Among the models, the model using L × W as independent variable had the highest prediction accuracy. Good accuracy was also obtained using the model with L alone, due to its lower D (0.27%), but the width model had a lower MSD than the length model.

Conclusion

The leaf surface area of muskmelon can be accurately estimated using simple linear regression models without the use of any expensive instruments, such as leaf area planimeter or digital photos with image measurement software. Various equations relating leaf length and/or width to leaf area applied in different muskmelon varieties had different performances in prediction accuracy, depending on the variation of leaf shape. All the models using length, width or their product could be used satisfactorily in the area estimation of Tianhun

Table 1. Estimated values of the leaf area K coefficients, standard error of K (SE_K), coefficients of determination (R^2), means square error (MSE) calculated by different models for muskmelon varieties Chioumih, Zhufen and Tianhun [z]

Model [y]	Chioumih				Zhufen				Tianhun			
	K	SE_K [y]	R^2	MSE	K	SE_K	R^2	MSE	K	SE_K	R^2	MSE
$A = K \times L^2$	0.74	0.016	0.979	926	0.68	0.010	0.989	545	0.62	0.011	0.986	454
$A = K \times L \times W$	0.73	0.011	0.989	499	0.65	0.007	0.994	289	0.67	0.011	0.988	403
$A = K \times W^2$	0.70	0.010	0.990	451	0.62	0.006	0.995	247	0.71	0.014	0.980	646

[z] 50 data points were used for each variety from the calibration data.
[y] A, leaf area; L, leaf length from the sinus base to the apex of leaf along midrib; W, maximum leaf width.

Table 2. Estimated values of the mean squared deviation (MSD), percentage of deviation for total area (D), and mean percentage of deviation for individual leaf area (MD) calculated by different models for muskmelon varieties Chioumih, Zhufen and Tianhun [z]

Model [y]	Chioumih			Zhufen			Tianhun		
	MSD [y] (cm)	D (%)	MD (%)	MSD (cm)	D (%)	MD (%)	MSD (cm)	D (%)	MD (%)
$A = K \times L^2$	2122	5.23	0.32	680	4.45	0.18	762	0.27	0.25
$A = K \times L \times W$	980	2.19	0.23	449	3.03	0.14	438	0.26	0.19
$A = K \times W^2$	632	1.23	0.18	608	1.34	0.17	451	0.67	0.18

[z] 50 data points were used for each variety from the validation data.
[y] A, leaf area; L, leaf length from the sinus base to the apex of leaf along midrib; W, maximum leaf width; K, leaf area coefficient.

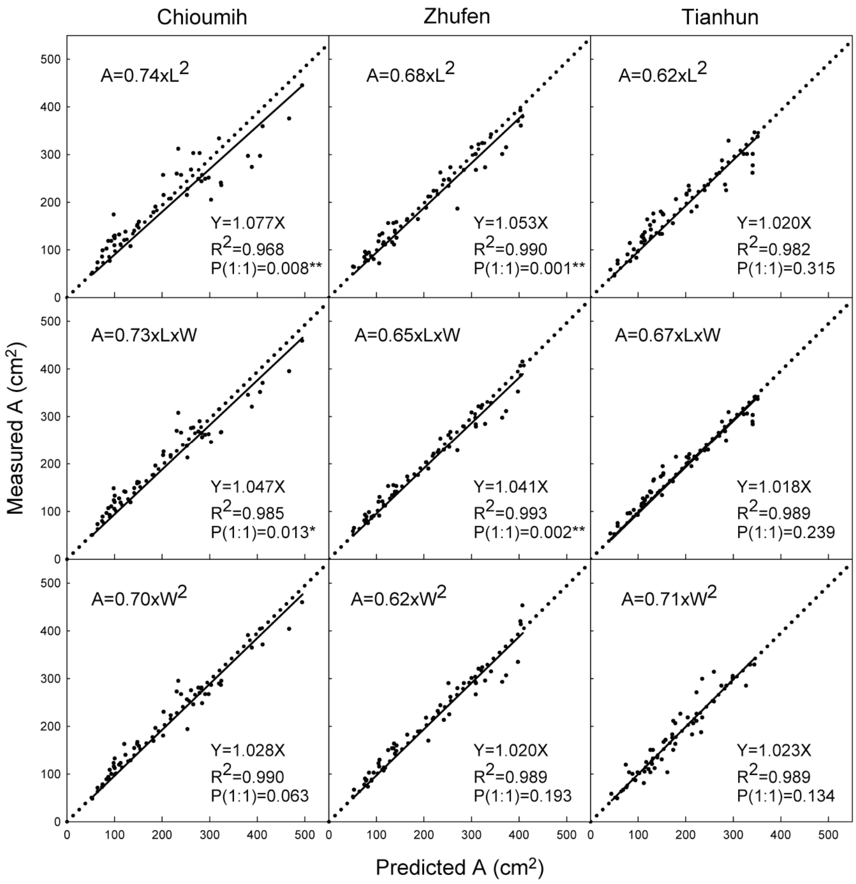

Fig. 2. Relationships between measured and predicted values of individual leaf areas of muskmelon from the validation data using different models for the varieties of Chioumih, Zhufen and Tianhun. Solid line represents linear regression line. Dashed line represents the 1:1 relationship between the measured and predicted values. P (1:1) is the probability that different from the 1:1 line. *, ** Significant at the 0.05 and 0.01 probability levels, respectively. 50 data points were used for each variety from the validation data. (A, leaf area; L, leaf length from the sinus base to the apex of leaf along midrib; W, maximum leaf width).

muskmelon, meaning that both width and length expansions increased the area expansion for a heart-shape leaf (Fig. 1). However, only the width model provided the highest accuracy in estimating the leaf area for Chioumih and Zhufen muskmelons with kidney shape and salient lobes (Fig. 1). This indicates that for a muskmelon leaf with kidney shape and salient lobes, the leaf area expansion is mainly determined by width (radial) expansion of the widest lobes.

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一種簡單經濟的洋香瓜葉面積估算技術 [1]

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摘　要

吳惠卿、陳烈夫、魏夢麗、呂秀英。2010。一種簡單經濟的洋香瓜葉面積估算技術。台灣農業研究 59:71–77。

葉面積是用來判斷洋香瓜生長發育的重要指標。本研究之目的在毋須使用任何昂貴的測量儀器下，以非破壞性取樣之方式，發展一個僅需測量葉片之長度及寬度的葉面積簡易估算模式。試驗材料為 3 個洋香瓜品種：天華 (Tianhun)、秋蜜 (Chioumih) 及朱芬 (Zhufen)，在農業試驗所 2007 年栽培期間取出各品種植株上各層植冠的葉片，測量其葉裂凹點至葉尖之主脈長 (L)、最大葉寬 (W) 及葉表面積 (A) 後，進行回歸分析 (regression analysis)。結果發現，3 個洋香瓜品種間的葉形迥異，影響了不同葉面積估算模式的預測準確度。針對秋蜜及朱芬兩個洋香瓜品種，回歸式中以 W^2 作為預測變數的葉面積估算模式具有最準確的預測效果，其估算係數分別為 0.70 及 0.62；而天華品種則以 $A = 0.67 \times L \times W$ 模式的預測準確度最高，其次 $A = 0.62 \times L^2$ 及 $A = 0.71 \times W^2$ 也在可接受誤差範圍內。這些模式所預測的葉面積與實測葉面積之間可達 1：1 關係，且其各種預測準確度統計量皆較低，如均方誤差在 451–762 之間、總葉面積誤差率≦1.34%、以及單葉面積平均誤差率≦0.25%。透過本研究所建立之線性回歸模式，可免於破壞植株生長，簡單、快速、經濟且準確地估算出洋香瓜的葉面積。

關鍵詞：葉面積、非破壞性估算、線性回歸模式、葉形、預測準確度。

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