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Morphological Model and Visual Characteristic of Leaf, and Fruit of Citrus (*Citrus sinensis*)

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Abstract

Citrus is a well-known horticultural plant and consumed. Leaf and fruit are important citrus organs as a fruiting plant. This is confirmed by the vitamin, antioxidant, and other chemical content of these organs which are beneficial for the human health. Understanding the model of both organs will facilitate the potential content, functional capacity and plant yield in non-destructive way. The study was aimed to determine morphological model and visual characteristic of leaf, and fruit of citrus. The study was conducted by comparing direct measurement and finding the relationship with selected predictors using several regression types (i.e. linear, linear with zero intercept, exponential, logarithmic, polynomial, polynomial with zero intercept and power). The observational sample consisted of 100 leaves and 13 fruits of citrus randomly collected from healthy, normal and productive plants. The results showed that leaf length (LL) × leaf width (LW) was the most reliable predictor using the linear regression with zero intercept (R^2= 0.991; y= 0.604x; RMSE= 0.34). Meanwhile, fruit circumference (FC) has been shown cannot be used as a predictor in determining fruit weight as indicated by low reliability. Based on the visual approach, ripe citrus is shown by the yellowish-green color of the peel along with the orange color of the pulp. Furthermore, in the middle of the ripened fruit pulp, there are also white stringy stuff. In conclusion, LL × LW with zero intercept regression is demonstrated the most reliability model for leaf area, while fruit circumference could not represent fruit weight.

Keywords: *Estimation model, morphological characteristic of citrus, non-destructive estimation, zero-intercept regression, RMSE.*

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INTRODUCTION

Citrus is a tropical fruiting plant with various benefits. One of the citrus benefits is found in leaf and fruit organs. Chi et al., (2020) reported that citrus peel contains essential oil that is beneficial as an antimicrobial. Zhang et al (2020) emphasized that citrus leaf provides the main material for producing essential oil which is higher than its peel. Citrus fruit, which is the main yield organ, has important benefits for health. Adenaike and Abakpa (2021) reported that citrus fruit contains bioactive and phytochemical components that are beneficial for immune system. This is in line with Lu et al., (2021) that citrus fruit contains vitamin and antioxidant which is beneficial for health.

A further understanding of plant traits modeling is important to be developed as an early approach to indicate the morphological and visual characteristics of its organs. Furthermore, morphological model and visual characteristics measurement can estimate the functional capacity and yield potential of the measured organ. This estimation can be applied conveniently and without destroying the plant organs. Some nondestructive models have been developed for leaf as in *Talium peniculatum* (Lakitan et al., 2021) and purple pakchoy (Fadhilah et al., 2022). The leaf modelling development involves to determine the leaf area. Leaf area is important to recognize the agronomic and

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physiological status of plant. Furthermore, Weraduwage et al. (2015) reported that leaf area can be an approach in determining plant biomass accumulation. Meanwhile, fruit model has also been reported in some cases such as olive fruit (Ponce et al., 2019) and tomato (Nyalala et al., 2019).

The development of morphological model and visual characteristic of leaf, and fruit of citrus that is applicable has not been improved yet. This modeling can serve as one of the considerations in decision making for cultivation practice. Moreover, the applicable model will ensure sustainability and provide a baseline for advanced modeling technologies. The study was aimed to determine an applicable model for morphological and visual characteristic of leaf, and fruit of citrus.

MATERIALS AND METHODS

Experiment Site

The research was carried out at Desember 2022 in Marga Sakti Sebelat (3°10'59"S-101°42'59"E), North Bengkulu, Bengkulu, Indonesia. The characteristic location was tropical and lowland rural area.

Research Procedure

The study used healthy, normal and productive citrus plant aged five years after planting (YAP). The citrus plant observed was directly planted in the farmer's field with normal fertilization and watering.

The leaf that was observed has varied in size and age. Meanwhile, the observed fruit was a ripe fruit of varying sizes. The total leaf number observed was 100 pieces while the fruit numbered was 13 units.

The measurement was carried out in the morning and the operation was carried out gradually. The leaves were taken every 10 (ten) pieces for each measurement to reduce risk of shriveled to resemble natural conditions on the stem.

At the end of the measurement, a root mean square error (RMSE) was calculated to test the predictor's accuracy by comparing the actual and predicted values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$$

with *Pi*; predicted value, *Oi*; observation value and *n*; amount of data measured. The lowest the RMSE value show more accurate of predictor.

Data Collection

The data was collected consists of leaf and fruit morphological data. The data related to leaf morphology i.e. leaf length (LL), leaf width (LW) and leaf area (LA). The LA was positioned as the dependent variable (y), while the LL and LW were positioned as independent variable (x). Meanwhile, the data that described fruit morphology was fruit circumference (FC) and fruit weight (FW). The FW was as the dependent variable (y), while FC was positioned as independent variable (x).

The LL was measured from the base to the tip of the leaf blade, while LW was measured at the widest part of the right to left side of the leaf blade. The FC was measured at centre section (Figure 1).

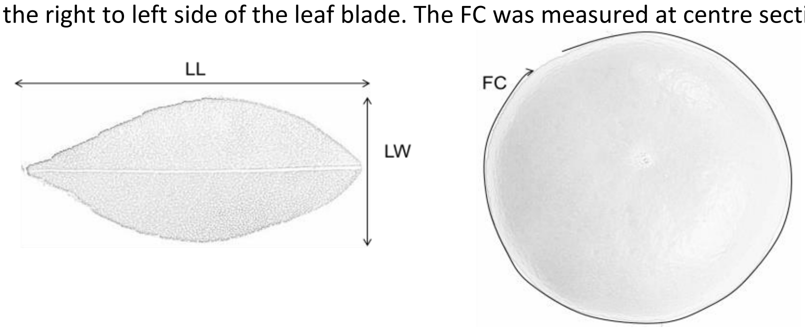

Figure 1. Representation Leaf (A) and Fruit (B) Measurement of Citrus.

The LA was measured using Easy Leaf Area for Android (Easlon and Bloom, 2014). Meanwhile, FC was measured using ruler tape and fruit weight was measured using digital scale. Visual recognition of leaf and fruit was carried out by capturing of each sample using a camera.

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Statistical Analysis

The simple regression was carried out to dicribe correlation each selected variables using Microsoft Excel for Windows 10.

RESULTS AND DISCUSSIONS

Citrus Leaf Morphological Characteristic

The citrus leaf variable measurement that can be directly observed are categorized as non-destructive and destructive parameters. Non-destructive parameter consists of leaf length (LL) and leaf width (LW), while leaf area (LA) is the parameter directly measured destructively.

The size of citrus leaf is medium and it is not too large. Meanwhile, the leaf shape of citrus also showed a high level of homogeneity. This was confirmed by the standard deviation and standard error of the LL, LW, and LA variable, which were relatively low (Table 1).

Table 1. Variation of Citrus Leaf Variable Measurement i.e. Leaf Length (LL), Leaf Width (LW) and Leaf Area (LA).

Variable \ Leaf Variable Measurement	Leaf Length (LL) (cm)	Leaf Width (LW) (cm)	Leaf Area (LA) (cm^2)
Minimum	4.40	2.00	5.42
Maximum	9.10	4.60	25.06
Average	6.38	3.30	14.20
Standard deviation	1.13	0.56	4.17
Standard error	0.11	0.05	0.42

As non-destructive parameters, leaf length (LL) and leaf width (LW) of citrus have a particular trait. Citrus leaves that have been classified by their length were confirmed as linearly correlated with leaf width. This was illustrated that an increase in each unit of leaf length was always followed by an increase in leaf width as well (Figure 2).

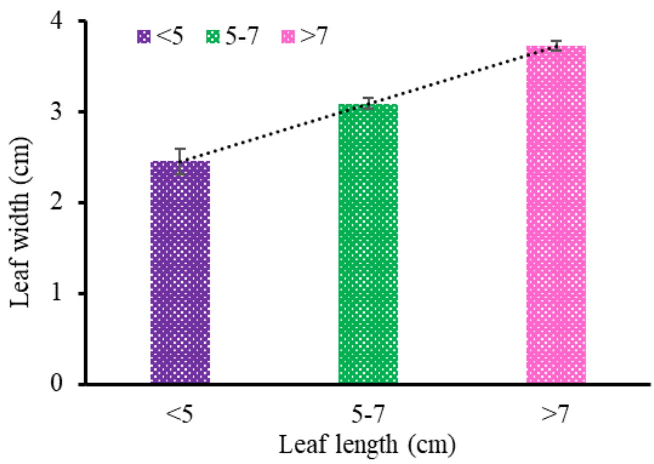

Figure 2. The Categorization and Correlation of Leaf Length (LL) on Leaf Width (LW).

Some non-destructive leaf variables measurement have often been tested as an option in leaf area estimation such as leaf length (LL), leaf width (LW), LL × LW and LL/LW. This provides an alternative for determining leaf area non-destructively.

The leaf length (LL) × leaf width (LW) as a predictor of leaf area was confirmed to be the most reliable among the other predictors. Furthermore, by using a linear regression with zero intercept model, this predictor became more reliable than other types of regression and predictors (R^2=0.992). This was supported by sufficient accuracy with minimum error of model estimation (RMSE= 0.134).

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The measurement variable for the leaf and fruit modeling is customized by their characteristics. The pinnate leaf has important measurement variable such as leaf length (LL) and leaf width (LW). This method was applied to kaffir lime leaf (Budiarto et al., 2021) and celery (Lakitan et al., 2021). Meanwhile, in palmate leaf, the lobe is the variable measurement to be considered. This was similar measurement in papaya (Zhou et al., 2020) and cassava (Lakitan et al., 2023). The research confirmed that the citrus leaf is pinnate. Hence, LL and LW are variable measurement that are important to modelling the leaf.

Table 2. Regression Type, Equation, Coeficient of Determination (R^2) and RMSE Between Leaf Predictor and Leaf Area (LA).

Leaf Predictors	Regression Type	Equation	R^2	RMSE
Leaf length (LL)	Linear	y = 3.3215x - 8.5142	0.814	0.179
	Linear with zero-intercept	y = 2.1093x	0.977	0.218
	Exponential	$y = 2.3154e^{0.2581x}$	0.785	0.196
	Logarithmic	y = 21.582ln(x) - 26.983	0.803	0.184
	Polynomial	$y = -0.0018x^2 + 3.3457x - 8.5937$	0.814	0.179
	Polynomial with zero intercept	$y = 0.1835x^2 + 0.7889x$	0.809	0.181
	Power	$y = 0.521x^{1.7068}$	0.810	0.182
Leaf width (LW)	Linear	y = 6.7517x - 8.3056	0.837	0.168
	Linear with zero-intercept	y = 4.3288x	0.978	0.217
	Exponential	$y= 2.3462e^{0.5256x}$	0.825	0.176
	Logarithmic	y = 20.966ln(x) - 10.721	0.814	0.179
	Polynomial	$y = 0.5874x^2 + 2.9251x - 2.2623$	0.840	0.166
	Polynomial with zero intercept	$y = 0.7954x^2 + 1.5344x$	0.839	0.166
	Power	$y = 1.8692x^{1.6652}$	0.840	0.166
Leaf length (LL) x Leaf width (LW)	Linear	y = 0.5505x + 1.3658	0.904	0.128
	Linear with zero-intercept	y = 0.604x	0.992	0.134
	Exponential	$y = 5.0796e^{0.042x}$	0.853	0.169
	Logarithmic	y = 11.741ln(x) - 22.16	0.893	0.136
	Polynomial	$y = -0.0042x^2 + 0.7487x - 0.7805$	0.908	0.126
	Polynomial with zero intercept	$y = -0.0029x^2 + 0.6827x$	0.907	0.126
	Power	$y = 0.7581x^{0.9306}$	0.905	0.128
Leaf length (LL)/ leaf width (LW)	Linear	y = -1.5109x + 17.319	0.006	3.471
	Linear with zero-intercept	y = 6.7778x	0.906	0.474
	Exponential	$y = 17.528e^{-0.125x}$	0.006	0.440
	Logarithmic	y = -2.395ln(x) + 15.921	0.004	0.436
	Polynomial	$y = -6.9093x^2 + 27.679x - 13.153$	0.033	0.431
	Polynomial with zero intercept	$y = -4.0496x^2 + 15.338x$	0.030	0.432
	Power	$y = 15.723x^{-0.209}$	0.003	0.441

Remark: coefficient of determination (R^2) indicated the level of reliability and Root Mean Squared Error (RMSE) indicated error rate.

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The regression model with highest reliability on each predictor namely leaf length (LL), leaf width (LW), LL × LW and LL/LW was selected to tested the best predictor. Nonetheless, each predictor has its level of reliability within leaf area estimation.

The data distribution of estimated leaf area and actual leaf area illustrated the accurate level of leaf area estimation. The estimated leaf area data with the predictor LL × LW by linear regression with zero intercept was indicated most closely following the regression line. Hence, this predictor with the regression is the most appropriate for estimating leaf area. Conversely, the LL/LW predictor showed estimated value further from the regression line, which confirmed that this predictor could not estimate leaf area (Figure 3).

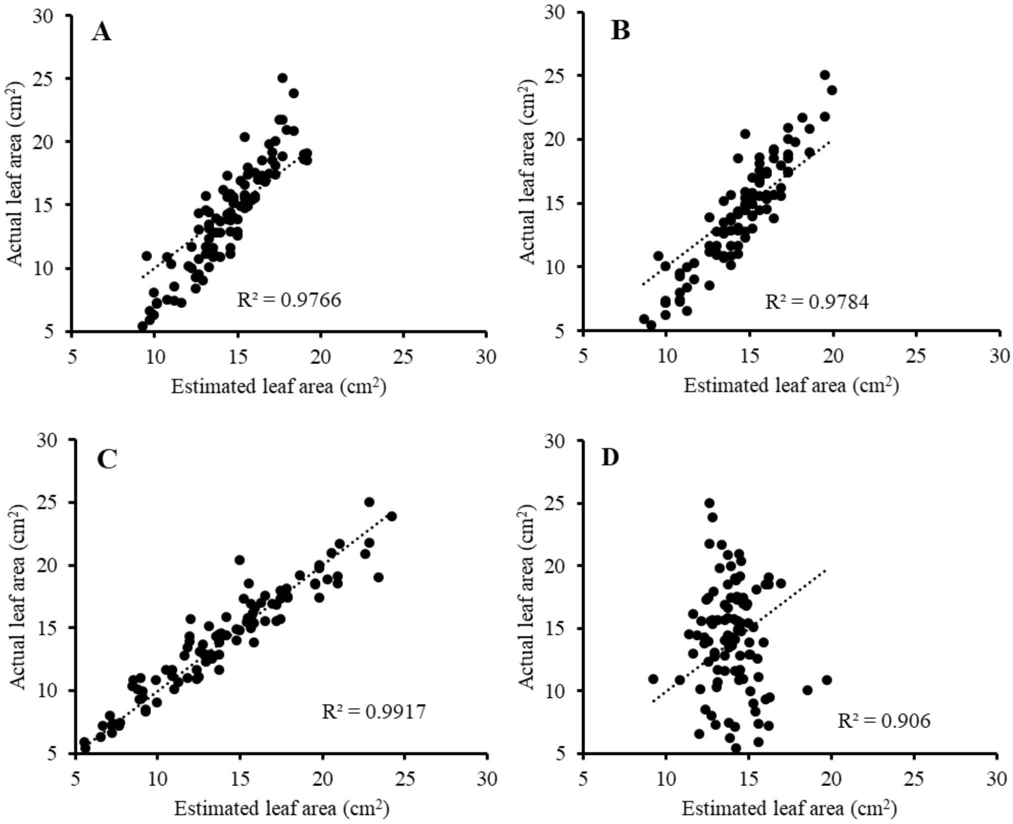

Figure 3. Comparison Four (4) Regression Model Between Actual Leaf Area with Estimated Leaf Area Through Selected Predictors I.E. Leaf Length (A), Leaf Width (B), Leaf Length × Leaf Width (C) and Leaf Length/Leaf Width (D).

Citrus Fruit Morphological Characteristic

The citrus fruit in some variable measurement has a certain variation level. The fruit's outer size that was represented by the fruit's circumference illustrates that ripe citrus has a high uniformity. This was demonstrated by the low standard deviation and standard error. However, citrus weight showed a high level of variation with the same indicators (Table 3).

Table 3. Variation of Citrus Fruit Variable Measurement i.e. Fruit Circumference (FC) and Fruit Weight (FW).

Fruit Variable Measurement / Variable	Fruit Circumference (FC)	Fruit Weight (FW) (g)
Minimum	16.80	71.10
Maximum	19.40	109.50
Average	18.09	91.22
Standard deviation	0.90	11.51
Standard error	0.25	3.19

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Based on the variety level, the citrus size may represent the citrus ripening level. In contrast, the portion of citrus fruit variables such as peel, fruit and seeds, which are related to fruit weight, cannot determine the citrus ripening level.

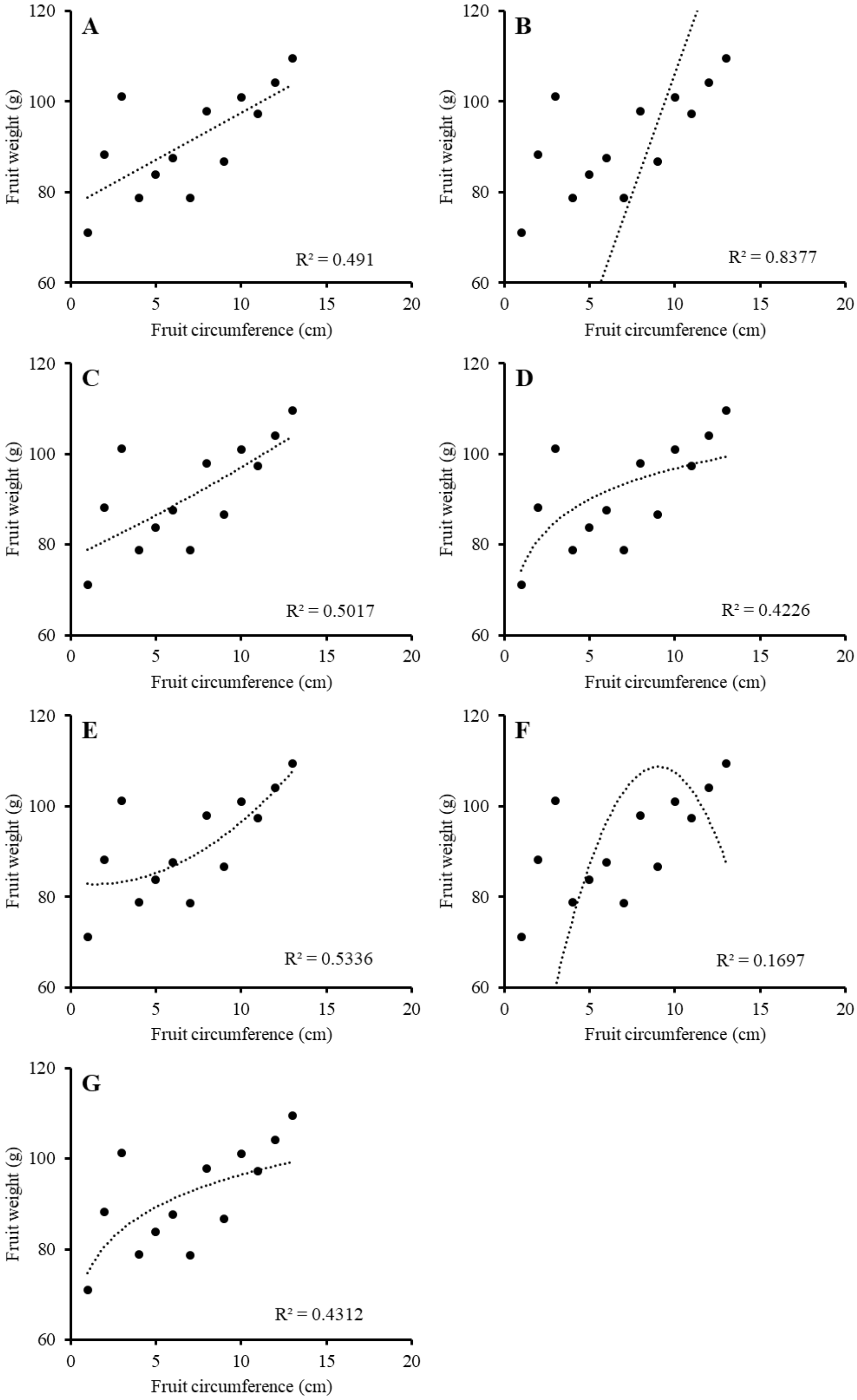

Figure 4. Correlation Between Fruit Circumference and Fruit Weight on Different Regression Types. The Regression Consists of: Linear Regression (A), Linear With Zero Intercept Regression (B), Exponential Regression (C), Logarithmic Regression (D), Polynomial Regression (E), Polynomial with Zero Intercept Regression (F) and Power Regression (G).

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The citrus fruit size cannot represent the ripe citrus fruit weight. The enhancement of fruit components such as peel, pulp and seed in ripe citrus, which are important components in determining fruit sized not always followed by fruit weight. It was assumed that there was an increased component but with a less weight. This was confirmed by the low reliability between fruit circumference and fruit weight in all regression types (Figure 4).

The variable measurement for interpreting the fruit is customized by the fruit shape. Colonna et al. (2019) reported that some Capsicum species have various options of variable measurement for their morphology model. Several options for fruit model measurement methods were also seen in olive-oil fruit (Ponce et al., 2019). The morphological model of citrus fruit with fruit circumference as a predictor was poorly confirmed. This phenomenon indicates that there is an important role for other predictors to play in citrus fruit weight prediction.

Visual Characteristic

Citrus is a plant with a characteristic leaf and fruit shape. The citrus leaf has a single leaf where each leaf consists of one blade. The citrus leaf has a pinnate leaf blade with a shape in the leaf mid-section larger than at the base and tip like a violin. On the other hand, ripe citrus fruit has been described as having a yellowish-green peel. Ripe citrus fruit have the pulp behind the peel. The citrus pulp has a color transformation from white when it is young to orange as it is ripening. There is a white layer in the middle of the fruit that looks like stringy stuff (Figure 5).

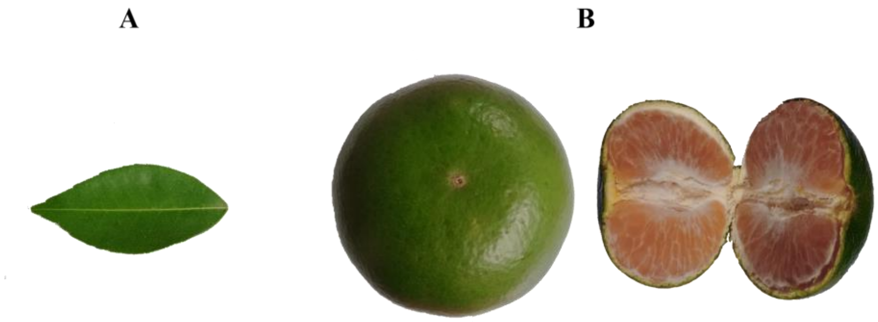

Figure 5. Visual Recognition of Leaf (A) and (B) Fruit of Citrus.

The leaf and fruit morphology of citrus has a distinctive. The citrus leaf morphology that can be known through a visual approach is color and shape. The citrus leaf is green and discoloration caused by several factors such as senescence, pest infestation and nutrient deficiency (Gonzalez-Gonzalez et al., 2021). Moreover, Budiarto et al. (2021) confirmed that the citrus leaf is classified as unifoliate. The citrus leaf is an important organ for plants with several mineral contents such as N, P, K, Ca, Mg, Fe, Cu, Zn, Na, and Mn (Khan et al., 2020).

Fruit is the yield organ for citrus plant. The citrus fruit is round like a ball with the pulp covered by the peel. Malik et al. (2012) stated that the citrus fruit has a spheroid to ellipsoid shape, which rounded at the top. The citrus peel contained waxes that has evolution as it matures (Ramero & Lafuente, 2020). The maturity level of citrus fruit has divided into several stages, namely normal, slight, moderate, and severe (Wu et al., 2020). Citrus fruit contain anthocyanins in specific amounts depending on the variety, while it has been experienced an anthocyanin modification when ripening (Piero et al., 2015).

Demirbas et al., (2020) stated that the citrus peel is proven to be able as an anti-microbial such as *Candida albicans, Staphylococcus aureus and Escherichia coli*. Furthermore, the citrus fruit have several nutrients which are beneficial for human health (Hussain et al., 2021). Based on observation, there are stringy white on ripe citrus. The stringy white is called albedo and are derived from the inner skin. The albedo provides water holding and swelling capacity in citrus fruits development (Multari et al. 2022). The observation confirmed that albedo has been attached to the fruit edge and also found in mid-site of fruit pulp.

The Benefits and Measurement Approach to Modelling Leaf and Fruit Morphology

Modeling is a method to create a simplified version to describe the real conditions. Modeling in plant, especially related to leaf and fruit morphology, can be beneficial in several ways. Price & Enquist (2006) reported that a modeling approach can predict plant biomass, including plant architecture. The

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morphological modelling also represents the plant growth expansion and can determine the plant area and fresh and dry weight (Basak et al., 2019). Recognizing the plant's response to environmental conditions is one reason for developing a plant morphology model. Blanchard et al. (2011) reported that the petunia response to certain environmental condition can be indicated by the plant's morphological model. In more advanced conditions, plant morphological models can indicated gene transcription in plants (Chen et al., 2010).

The creation of plant morphology models is customized to the representation purpose. Meanwhile, the predictor organ is selected to be most capable for representing the plant's growth and yield. The leaf as an organ that plays an important role in the plant's physiology, has different characteristics among plants. This was confirmed in several plants such as, spinach (Mahanti et al., 2020), wheat (Boussakouran et al., 2019) and oaks (Ramirez-Valiente et al., 2019). In some plants, fruit modeling was also studied as a yield organ. This was reported in tomato (Rowland et al., 2019) and pomegranate (Farsi et al., 2023).

Several regression types can be approaches in modeling the real situation. Okpo et al (2020) reported that simple regression has performed well to represent the real conditions. Furthermore, Lakitan et al. (2022) emphasized that several regression types such as linear, polynomial, exponential, logarithmic and power regression can be selected to describe the plant organs. The coefficient of determination (R^2) is a reflection of correlation between the predictor and the real condition. Kumar and Chong (2018) emphasize that the R^2 value is between -1 to 1. The higher of R2 value indicates the predictor has a strong correlation with the real condition.

The linear with zero intercept regression was chosen as the most reliable for modeling citrus leaf area. This was also confirmed by Widuri et al. (2017) reported that the linear with zero intercept regression was the most reliable to modelling the chili leaf area. Scmidt and Finan (2018) assumed that in regression with zero intercept if x=0, then y=0. Regarding that assumption, it logically confirm that if one of the citrus leaf measurement variables is 0 then the leaf area is 0 as well. The reliability was enhanced by the low RMSE value. The lower RMSE value represents the lower error rate of the model when representing the real situation. This has been demonstrated in several research cases (Basak et al., 2019; Kowalczyk-Juśko et al., 2020).

CONCLUSION

Based on the observation, the morphological model of citrus leaf can be observed through simple regression. The leaf length (LL) × leaf width (LW) provides a predictor for determining leaf area by the linear with zero intercept regression type (R^2= 0.992; RMSE=0.134). Visual characteristics of citrus leaf revealed a pinnate leaf shape. Meanwhile, Fruit circumference (FC) has yet to prove as predictor to determine fruit weight.

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