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Mass modeling of Malaysian varieties Pomelo fruit (*Citrus Grandis* L. Osbeck) with some physical characteristics

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Abstract

Knowledge of physical characteristics of Malaysian variety pomelo fruits are necessary for the design of some post harvesting, processing systems such as cleaning, handling, grading and packaging system. For proper development of pomelo grading systems, important relationships between the mass and some physical characteristics of pomelo fruits such as length, width, thickness, surface area, projected areas and volumes must be known. The aim of this research was to measure physical characteristics of two Malaysian varieties of pomelo fruit; Ledang (PO55) and Tambun (PO52) varieties. In this study, the mass of pomelo fruit was evaluated and correlated to measure physical characteristics using Linear, Quadratic, S-curve and Power models. The results showed that the correlation of the mass of pomelo fruit with all measured physical characteristics was significant at the 0.01 probability level. In the nutshell, mass modeling of pomelo fruit for Ledang (PO55) and Tambun (PO52) varieties based on the projected area are recommended according to economical view.

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Introduction

Pomelo is originally from Malaysia and one of the best fruits of South East Asia (Morton, 1987). Pomelo is believed to be an ancestor of grapefruit, rounded with a rather thick skin and most stable of all citrus varieties in storage which have more endurance for both long storage period and export. Furthermore, it also rich with vitamin A, B1, and C from its juicy pulp (Chomchalow *et al*., 2008). In Malaysia, pomelo fruit also called as limau bali, pummelo, limau betawi, shaddock or limau besar which belongs to family of Rutaceae (Scora, 1975; Morton, 1987). The fruit is widely grown in the states of Johor, Perak, Kedah, Melaka and Kelantan. There are few popular varieties of pomelo in Malaysia which known as PO52 (Tambun), PO51 (Sha Thing), KK2 (Melomas) and new hybrid known as Ledang (PO55) which has introduced by Department of Agriculture Malaysia.

Physical attributes of agricultural products such as fruits usually graded based on size, shape, volumes, weight and area of projection. The knowledge about these physical characteristics and their correlations are applicable for the scheme of handling, sorting, grading or packaging process (Safwat, 1971; Peleg and Ramraz, 1975; Mohsenin, 1986). Physical characteristics also affect consumer acceptance where fruits with similar shape and identical mass are most favored. Grading based on mass of fruit can help in reducing packaging and shipping expenses, and may perhaps offer an optimal packaging design (Peleg, 1985).

Fruits generally are graded according to their size, shape, colour and variety. Usually fruits are graded based on size observation such as small, medium, large and extra large while on the basis of fruit's maturity; they are graded as immature, properly mature and over mature (Anonymous, 2011). Manual and size grading are common methods, but researches in the fieldwork of fruit grading recently paying attention on the strategies of automated grading to eliminate any man errors during processes. It was offered more effective and precise grading systems which enhance the categorization success or accelerate the procedure (Kleynen *et al*., 2003; Polder *et al*., 2003).

Grading mechanism by electrically is more expensive and quite complex, while mechanical grading mechanisms are work slowly. With respect to the economical importance of pomelo fruit and its need for a grading process, development of suitable mechanism for grading of pomelo fruit is necessary. Consequently, it perhaps more cost-effective and recommended in fabricate a machine, where fruits are grading by weight mechanism for fruits with irregular shape. Determining the correlations between mass with their physical characteristics might be applicable since this method is more precise for automatic classification for most fruits (Marvin *et*

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al., 1987; Stroshine and Hamann, 1995); Khoshnam *et al*., 2007)

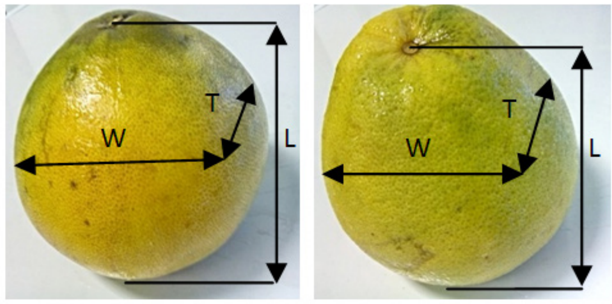
Several researches have been performed in the case of mass modeling of fruits with some of their physical characteristics. Tabatabaeefar *et al*. (2000) found a few mass models of orange fruit according to their physical attributes. Lorestani and Tabatabaeefar (2006) published models for estimating mass of Iranian kiwi fruit and they performed that the intermediate diameter of fruit was the best fitted model while Khanali *et al.* (2007) achieved mass models for tangerine. The best model for grading system of onion mass was obtained based on length as nonlinear relation $M = 0.035a^2 - 1.64a + 36.137$, $R^2 = 0.96$ which has been studied by Ghabel *et al*. (2010). The other study of mass modeling of sweet lemon, width dimension, projected area perpendicular to length and ellipsoid assumed shape volume are the most appropriate model (Garavand, 2010). Study for estimating tomato mass by Izadi *et al*. (2013), showed that model which is based on ellipsoid volume give the best results but statistical results of study by Keshavarzpour and Rashidi (2011) indicated that the linear regression models under predict mass of apple and cannot be appropriately used. In addition, study the mass of Castor seed variety (Lorestani *et al*., 2012), mass of Ziziphus (Lorestani *et al*., 2013) and mass of two variety Iranian apricot (Rajabali and Ghavami) varieties (Mirzaee *et al*., 2008) were predicted using four models which includes Linear, Quadratic, S-curve, and Power model while Mansouri *et al*. (2010) were predicted mass and surface area of pomegranate fruit using linear model.

The focus of this study is to find out the best fitted model in estimating two Malaysian varieties of pomelo fruit mass, Ledang (PO55) and Tambun (PO52) varieties by its physical attributes since no particular studies considering mass modeling on pomelo characteristics have yet been established. This information can be used in the design and evaluation of grading mechanism for some researchers and designers.

Materials and Methods

Fresh harvested pomelo fruits used in this study were obtained in November 2013 where Ledang variety (PO55) was obtained from Jabatan Pertanian Daerah Segamat, Johor Darul Takzim, Malaysia and Tambun variety (PO52) was obtained from Jabatan Pertanian Daerah Kinta, Ipoh, Perak Darul Ridzuan, Malaysia. Healthy samples and free from any injuries were randomly selected from both varieties of pomelo for determination of their physical characteristics.

The mass of pomelo fruits for both varieties were evaluated using a digital balance with accuracy of 0.01 g. Three principal of dimensions (Figure 1),



a) b)

Figure 1. Dimensional characteristics of pomelo, length, L, thickness, T, width, W; (a) Ledang variety (PO55), (b) Tambun variety (PO52)

namely length, thickness and width were measured by using a digital caliper with an accuracy of 0.01 mm. The measured volume of pomelo fruit was determined by method of water displacement, while geometric mean diameter and surface area of fruits were determined using suggested equation by Mohsenin (1986).

$$Dg = (LWT)^{1/3} \quad (1)$$

$$S = \pi (Dg)^2 \quad (2)$$

Where: L is length (mm), T is the thickness (mm), W is the width (mm), S is the fruit surface area (mm²) and Dg is geometric mean diameter (mm) of pomelo fruit.

Projected areas of pomelo fruits are perpendicular to dimensions which were calculated by using equation (3), (4) and (5), respectively. Then, the average projected area known as criteria projected area (CPA) was determined from equation (6) (Mohsenin, 1986; Rashidi and Gholami, 2011).

$$PA_L = \frac{\pi LW}{4} \quad (3)$$

$$PA_T = \frac{\pi TW}{4} \quad (4)$$

$$PA_W = \frac{\pi WW}{4} \quad (5)$$

$$CPA = \frac{PA_L + PA_T + PA_W}{3} \quad (6)$$

Where: PA_L (perpendicular to length of fruit), PA_T (perpendicular to thickness of fruit) and PA_W (perpendicular to width of fruit).

Method of water displacement was used to determine the fruits measured volume (V_m) and the pomelo fruit was then assumed as oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes according to Shahbazi and Rahmati (2012). Their volumes were calculated as following equations (Luther *et al*., 2004)

$$Vosp = \frac{4}{3}\pi\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2 \quad (7)$$

$$Vellip = \frac{4}{3}\pi\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \quad (8)$$

After determination of the dimensions, mass, projected areas and volume, SPSS 21 program were used for regression analysis. In order to estimate mass models of pomelo fruit, the following models were considered:

- Single or multiple variable regression of pomelo fruit mass based on fruit dimensional characteristics, including length (L), width (W), thickness (T), geometric mean diameter (Dg) and surface area (S)
- Single or multiple variable regression of the pomelo fruit mass based on fruit projected areas (PA_L, PA_T, PA_W) and criteria projected area (CPA)
- Single or multiple variable regression of the pomelo fruit mass based on measured volume (V_m), the volume of the pomelo fruit which assumed as oblate spheroid shape (V_{osp}) and volume ellipsoid shape (V_{ellip}).

Four regression models involved in this study, including: Linear, Quadratic, S-curve and Power models were used for mass prediction of pomelo fruits based on measured physical characteristics, as are represented in the following equations, respectively:

$$M = b_0 + b_1X \quad (9)$$

$$M = b_0 + b_1X + b_2X^2 \quad (10)$$

$$M = b_0 + \frac{b_1}{X} \quad (11)$$

$$M = b_0\, X^{b_1} \quad (12)$$

Where: M is mass (g), X is the value of a parameter (physical characteristics) to find its correlations with pomelo fruit mass, b_o and b_1, b_2 and are curve fitting constants.

Results and Discussions

Physical characteristics of Pomelo fruit variety Ledang (PO55) and Tambun (PO52)

The average values of physical characteristics of pomelo fruit for two varieties, Ledang (PO55) and Tambun (PO52) are shown in Table 1. As shown from the results obtained, the correlations of physical characteristics, with the pomelo fruit mass, are significant at the 0.01 level. Based on the obtained data, the average values of several physical characteristics which were length, thickness, width, geometric mean diameter, surface area, projected areas, measured volume, volume assumed oblate spheroid and ellipsoid shape for Tambun (PO52) variety were significantly greater than Ledang (PO55) variety. But the mean value of mass for Tambun (PO52) variety (1297.4 g) was less than the mass of Ledang (PO55) variety (1357.0 g). This is might be due to the difference in the morphology and cavity volumes of fruit cause variation in their physical attribute as stated by Seyedabadi *et al.* (2011) in their study on Tile Magasi and Tile Shahri melons.

Mass modeling

Table 2 displays the best fitted models obtained and their coefficient of determination (R^2) for mass prediction of two Malaysian varieties of pomelo fruit according to their calculated physical characteristics. Coefficient of determination (R^2) value was used to evaluate the regression models where higher (R^2) value near to 1.00 shows the better fit model.

Modeling based on dimensions

For Ledang variety (PO55), width (W), geometric mean diameter (Dg) and surface area (S) showed that Linear and Quadratic model used to calculate mass of pomelo, while the best fitted model for length (L) and thickness (T) showed only Quadratic and Power model to evaluate mass of pomelo fruit, respectively. Length of pomelo fruit had the highest R^2 among the others as given as Quadratic form:

$$M = 28500.33 - 417.191\, L + 1.587\, L^2$$

Similar model for onion suggested by Ghabel *et al.* (2010), they were reported that the Quadratic model was the best model for the mass determination based on length as $M = 0.035L^2 - 1.64L + 36.137$, $R^2 = 0.96$.

The results obtained for mass modeling of pomelo fruit based on dimensional characteristics which includes length (L), width (W), thickness (T), geometric mean diameter (Dg) and surface area (S) showed that Quadratic model was the best fitted model to calculate the mass of pomelo fruit Tambun variety (PO52). Dimensional characteristics based on width (W) had the value of R^2 close to unity among the others dimensions as shown in following equation:

$$M = -17135.64 + 217.121\, W + 0.635\, W^2$$

Thus, pomelo mass modeling based on width is recommended which similar with the model reported by Tabatabaeefar *et al.* (2000) and Khanali *et al.* (2007) concerning mass prediction of orange and tangerine fruit, respectively. Their recommended model was $M = 0.069b^2 - 2.95b - 39.15$, $R^2=0.97$ for orange while for tangerine was $M = 0.07b^2 - 3.78b +$

Table 1. Physical characteristics of two Malaysian varieties of pomelo fruits (Ledang and Tambun)

		Parameters												
Variety	Statistical values	L (mm)	T (mm)	W (mm)	M (g)	Dg (mm)	S (mm^2)	PA_L (mm^2)	PA_T (mm^2)	PA_W (mm^2)	CPA (mm^2)	V_m (cm^3)	V_{osp} (cm^3)	V_{ellip} (cm^3)
LED	Minimum	137.2	143.0	154.7	1136.0	147.1	68046.3	17080.5	17447.3	18815.7	18016.5	1050.0	1796.5	938.9
	Maximum	149.2	149.1	159.8	1588.0	151.7	72363.1	18694.2	18569.4	20058.5	19024.5	1345.0	1987.8	1029.6
	Mean	144.1	146.2	156.7	1357.0	148.9	69667.3	17741.7	18002.2	19300.9	18348.3	1194.0	1854.1	972.7
	Stdev.	3.6	1.8	1.6	129.4	1.2	1136.9	439.0	358.1	403.1	288.1	67.6	52.5	23.9
TAM	Minimum	142.8	150.4	150.0	1145.0	148.8	69599.8	16833.7	18022.2	17678.5	17546.9	1120.0	1683.7	971.2
	Maximum	175.4	179.2	169.5	1423.0	168.8	89493.4	23362.4	23138.3	22580.7	22274.9	1372.0	2640.9	1416.1
	Mean	154.8	158.6	157.1	1297.4	156.8	77370.1	19139.0	19599.9	19431.8	19390.2	1196.3	2011.1	1140.6
	Stdev.	8.7	6.9	5.8	86.7	5.9	5948.1	1691.3	1359.3	1453.9	1414.9	73.2	250.9	133.1
Total Observation	Minimum	137.2	143.1	150.0	1136.0	147.2	68046.3	16833.7	17447.4	17678.6	17546.9	1050.0	1683.7	938.9
	Maximum	175.4	179.2	169.6	1588.0	168.8	89493.4	23362.4	23138.3	22580.7	22274.9	1372.0	2640.9	1416.1
	Mean	149.5	152.4	156.9	1327.2	152.9	73518.8	18440.4	18801.1	19366.4	18869.3	1195.2	1932.6	1056.7
	Stdev.	8.5	8.0	4.2	112.4	5.8	5748.8	1406.7	1270.5	1050.4	1134.6	69.2	195.2	126.9

73.80, R^2=0.83. Garavand (2010) determined models for predicting mass of sweet lemon also based on width as M= - 0.002b² + 6.0386b – 239.58, R^2=0.8566

Modeling based on areas

Among the investigated models based on projected areas (PA_L, PA_T, PA_W) and CPA), Quadratic model of the projected area based on length and criteria projected area (CPA), shown in Table 2, both had the value of R^2 = 0.999 for Ledang (PO55) and Tambun variety (PO52), respectively. For Ledang variety (PO55), the best model showed to calculate mass of pomelo fruit as

$$M = -20031.46 + 2.116\, PA_L - 5.13\, x10^{-5} PA_L{}^2$$

while for Tambun variety (PO52) as

$$M = -3209.32 + 0.397\, CPA - 8.5\, x10^{-6}\, CPA^2$$

Also, the mass modeling recommended for sizing tomato fruit and sour orange fruit based on any one of the projected area were reported by Taheri-garavand *et al.* (2011) and Shahbazi and Rahmati (2012) respectively.

However, for Tambun variety (PO52), measurements of all the three projected areas of fruit are necessary if the above model use for grading of pomelo fruits. This will make the sizing mechanism more complex and leads to the reduction in speed of processing and also increasing of grading system costs. It is evident that one of the projected areas must be selected. Among the PA_L, PA_T, PA_W projected areas, Quadratic model of PA_W were preferred because of the high value of R^2 compare to PA_l, PA_T presented as: $M = -4159.61 + 0.491\, PA_W - 1.08\, x10^{-5} PA_W{}^2$; R^2 = 0.997

Modeling based on volumes

Among the results obtained in Table 2 where mass prediction of the pomelo fruit based on volumes (V_m, V_{osp} and V_{ellip}), the Quadratic model showed the best model for both varieties, Ledang (PO55) and Tambun (PO52) based on the highest value of R^2 compare to the other models. For Ledang variety (PO55), not only Quadratic form showed the best fitted model but Linear and S-curve model also can be used to identify the mass of pomelo fruit. Among the three volumes, measured volume, V_m given the highest value of R^2 which is 0.999 for Ledang variety (PO55), while for Tambun variety (PO52), volume assumed shaped as oblate spheroid, V_{osp} given the highest value of R^2 which is 0.989. The following equation shows the best models formed for both varieties of pomelo fruit:

Ledang (PO55): $M = -465.83 + 0.002\, V_m$ (Linear);

$M = -864.47 + 0.002\, V_m - 2.79\, x\, 10^{-10}$ (Quadratic);

$M = 8.559 - (\frac{1601104.08}{Vm})$ (S-curve)

Tambun (PO52):

$$M = -808.43 + 0.002\, V_{osp} - 3.31x\, 10^{-10} V_{osp}{}^2$$

Furthermore, Garavand (2010) and Seyedabadi *et al.* (2011) stated that in measuring the actual volume is time consuming task and quite unreasonable, so they were suggested to model the mass of sweet lemon and cantaloupe based on the volume of assumed ellipsoid shape and oblate spheroid shape, respectively. Therefore, the mass modeling based on volume of assumed oblate spheroid shape was seems suitable be accomplished for Ledang variety (PO55), even the value of R^2 is lower than others. This is because only length and width measurement involved in the determination of volume assumed oblate spheroid shaped compare to volume assumed

Table 2. The best fitted models for mass prediction of two variety pomelo fruit (Ledang and Tambun) with some physical characteristics

No	Dependent Variable	Independent variable	Variety	The best fitted model	Constant parameter			R^2
					b_0	b_1	b_2	
1	M (g)	L (mm)	LED	Quadratic	28500.33	-417.191	1.587	0.993
			TAM	Quadratic	-6149.67	85.785	-0.243	0.993
2	M (g)	T (mm)	LED	Power	1.11×10^{-14}	7.884	-	0.979
			TAM	Quadratic	-12978.07	164.639	-0.47	0.997
3	M (g)	W (mm)	LED	Linear	-12516736	88.349	-	0.986
				Quadratic	-12516736	88.349	-	0.986
			TAM	Quadratic	-17135.64	217.121	0.635	0.998
4	M (g)	Dg (mm)	LED	Linear	-12674.03	94.097	-	0.964
				Quadratic	-12674.03	94.097	-	0.964
			TAM	Quadratic	-15625.79	200.152	-0.587	0.977
5	M (g)	S (mm²)	LED	Linear	-5634.87	0.1	-	0.963
				Quadratic	-5634.87	0.1	-	0.963
			TAM	Quadratic	-3694.70	0.113	-6.27×10^{-7}	0.975
6	M (g)	PA_L (mm²)	LED	Quadratic	-20031.46	2.116	-5.13×10^{-5}	0.999
			TAM	Quadratic	-2316.31	0.325	-7.06×10^{-6}	0.973
7	M (g)	PA_T(mm²)	LED	Quadratic	7411.81	-1.076	4.10×10^{-5}	0.998
				Power	1×10^{-13}	5.369	-	0.998
				S-curve	12.571	-96593.38	-	0.998
			TAM	Quadratic	-5359.42	0.6	-1.33×10^{-5}	0.996
8	M (g)	PA_W(mm²)	LED	Quadratic	-44941.07	4.405	-	0.998
			TAM	Quadratic	-4159.61	0.491	-1.08×10^{-5}	0.997
9	M (g)	CPA (mm²)	LED	Linear	-6406.15	0.421	-	0.947
				Quadratic	-6406.15	0.421	-	0.947
			TAM	Quadratic	-3209.32	0.397	-8.50×10^{-6}	0.999
10	M (g)	V_m (mm³)	LED	Linear	-465.83	0.002	-	0.999
				Quadratic	-864.47	0.002	-2.79×10^{-10}	0.999
				S-curve	8.559	-1601104.08	-	0.999
			TAM	Quadratic	-8511.81	0.015	-5.58×10^{-9}	0.903
11	M (g)	V_{osp}(mm³)	LED	Quadratic	-49056.76	0.051	-1.29×10^{-8}	0.993
			TAM	Quadratic	-808.43	0.002	-3.31×10^{-10}	0.989
12	M (g)	V_{ellip} (mm³)	LED	Quadratic	-35880.69	0.071	-3.35×10^{-8}	0.996
			TAM	Quadratic	-1256.68	0.004	-1.33×10^{-9}	0.972

ellipsoid shaped and actual volume method. Therefore, the recommended mass model shown as Quadratic form. $M = -49056.76 + 0.051\, V_{osp} - 1.29 \times 10^{-8} V_{osp}^{\ 2}$

Conclusion

Some physical characteristics of Malaysian variety pomelo fruit, Ledang variety (PO55) and Tambun variety (PO52) are performed in this study together with their relationships with the mass of fruits. Based on this study it can be concluded that the all characteristics were found to be statistically significant at the 0.01 probability level. Mostly the best fitted model is Quadratic model which can estimate the correlations between the mass and physical characteristics of pomelo fruits with appropriate coefficient of determination values, R^2. Ultimately, the model with Quadratic form by referring to the projected areas perpendicular to length *(PA_L)* for Ledang variety (PO55) and projected area perpendicular to the width *(PA_W)* for Tambun variety (PO52) were suggested because only need to assess several dimension of fruit. Hence, the value of suggested mass modeling for Malaysian pomelo of Ledang variety (PO55) and Tambun variety (PO52) were $M = -20031.46 + 2.116\, PA_L - 5.13 \times 10^{-5} PA_L^{\ 2}$ and $M = -4159.61 + 0.491\, PA_W - 1.08 \times 10^{-5} PA_W^{\ 2}$, respectively. It can be used as the primary measurement of the grading system beside it is appropriate and economic method.

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