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Some Engineering Properties of Pineapple Fruit

Rosnah Shamsudin
Universiti Putra Malaysia

Hasfalina Che-Man
Universiti Putra Malaysia

Siti Hajar Ariffin
Universiti Putra Malaysia

Siti Nor Afiekah Mohd-Ghani
Universiti Putra Malaysia

Nazatul Shima Azmi
Universiti Putra Malaysia

Abstract: Pineapple is a tropical fruit that is highly relished for its unique aroma and sweet taste. In contrast to other tropical fruits, pineapples typically feature medium-sized fruits with yellow flesh. Based on the physical properties of pineapple fruit variety MD2 such as dimensions, geometric mean diameter (D_g), arithmetic mean diameter arithmetic mean diameter (D_a), surface area, volume, sphericity, aspect ratio, and projected area and the best-fit mass models have been determined. From the result obtained, the physical properties such as length, thickness, width, D_g, D_a and circumference were found to be 217.8mm, 132.7mm, 132.9mm, 156.5mm, 161.2mm, 394.3mm respectively. Meanwhile for the aspect ratio, mass, volume surface area, sphericity and projected area perpendicular to dimension namely PA_L, PA_T, AND PA_W were found to be 0.61, 1730.4g, 1420 cm^3, 77107.4 mm^2, 0.72, 22746.0 mm^2, 13942.9 mm^2, and 16866.3 mm^2 respectively. For all physical properties except volume, the best fit mass model to predict mass of pineapple fruits was the quadratic model. Additionally, the findings demonstrated that, in comparison to other attributes, the mass model based on actual volume was more appropriate, with the highest determination coefficient (R^2) for Quadratic and S-curve model. For developing and optimizing machinery for handling, maintenance, distribution, and storage, the mass model of pineapple fruits according to the actual volume in the outcomes is relatively important.

Keywords: Pineapple, MD2 variety, Physical properties, Mass model

Introduction

Pineapple or Ananas comosus is a tropical fruit that is highly relished for its unique aroma and sweet taste. It is originally from the American tropics and is a member of the botanical family Bromeliaceae (Izli et al., 2012). Typically, pineapple fruits have yellow flesh colour and are relatively medium in size compared to other tropical fruits. They are made up of many fruitlets and have a distinct maturation pattern from the top near the crown to the bottom of the fruit that determines the maturity level and the time of harvesting. The evaluation based on physical, physicochemical, and chemical attributes of fruit with acceptable flavour and morphological characteristics is used as maturity indicators (Nadzirah et al., 2012). Pineapples can be found all over the world with many regions of pineapple plantations. According to the Malaysian Pineapple Industry Board (MPIB), in 2019, Costa Rica is the biggest producer of pineapples with 3,328,100 MT of pineapples produced followed by Philippines and Brazil with 2,747,856 MT and 2,426,526 MT respectively, while Malaysia is in 22nd place in

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the world with 299,912 MT. There are more than 100 varieties of pineapple fruits available in the world but only 6 to 8 varieties are grown commercially (Steingass et al., 2020). In Malaysia, the most common cultivated varieties include Morris, Sarawak, Josaphine, Gandul, Yankee, Masphine, N36 and the most recent, MD2 (Lasekan et al., 2018).

Due to its great flavour, sweetness, golden flesh and skin colour, and ideal cylindrical shape, pineapple variety MD2 is currently the most widely traded variety in the world of international commerce (Shafawi et al., 2020). In addition, pineapple fruit variety MD2 has smaller fruits with an average weight of 1.5 kg, a constant bright gold colour, a sweeter flavour, four times as much vitamin C, less fibre, and less acidity. Its shelf life is also longer.

Before being marketed, pineapples were often classified according to a certain grade based on their mass or size. Due to this, it is essential to determine the relationship between the physical properties to design and optimise a grading machine. Furthermore, the design of other postharvest processing processes, including as handling, sorting, cleaning, transporting, and packaging, depends on the physical characteristics of fruits and their interactions. According to Shahbazi & Rahmati (2020), in comparison to electrical grading systems, which are more complicated and expensive, and mechanical systems, which operate slowly, weight-based grading may be more cost-effective. Therefore, creating a system of rating fruits according to their mass may be practical and applicable. Dimension, mass, volume, and estimated area are the factors that will have the biggest impact on how the grading system is designed. Grading operations based on mass can be achieved by using appropriate models based on the fruit's physical properties. The common regression relationships used in previous studies were Linear, Quadratic, S-curve, and Power models. Thus, this study was undertaken to determine the physical properties (dimensions, D_g, D_a, surface area, volume, sphericity, aspect ratio, and projected area) of pineapple fruit specifically 'MD2' variety and fit into the best mass model.

Material and Methods

Raw Materials

Five pineapple fruits variety MD2 were supplied and harvested from the local farm located in Sg. Merab, Kajang, Selangor, Malaysia on the same day. The fruits chosen were from indices 4 (ripe) which were free from damage and pests. Thus, only mature and healthy fruits were chosen for the conduct of this experiment. The fruits were then stored in room conditions until further used.

Determination of Dimension and Shape of Pineapple Fruit

The three principal dimensions namely length (L), width (W) and thickness (T) were measured as in Figure 1 for each pineapple fruit by using the thread and ruler (accuracy 1 mm). The measurements of the L, W and T of the whole fruit of the pineapple MD2 variety were done. The principal dimensions were measured for five whole fruits and the average value was calculated.

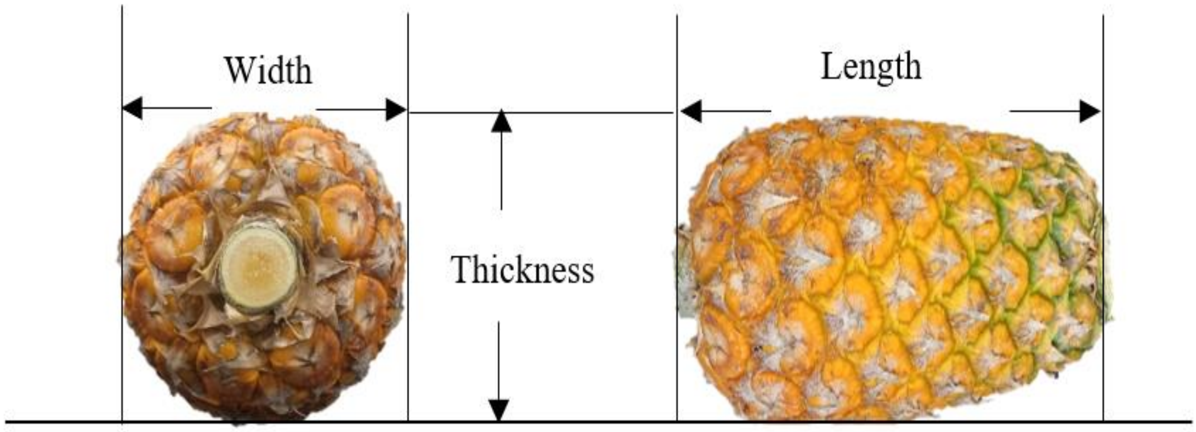

Figure 1. Dimensions of pineapple fruits variety MD2

Determination of Geometric Mean Diameter (Dg) and Arithmetic Mean Diameter (Da)

D_g and D_a of 5 pineapple fruits were determined using the measured dimensions of L, W, and T. D_g and D_a were then calculated by the following relationships Equations (1) and (2) given by Lorestani (2012), and Zainal A'Bidin et al. (2020).

$$D_g = (LWT)^{\frac{1}{3}} \quad (1)$$

$$D_a = \frac{L+W+T}{3} \quad (2)$$

Where L is the length in mm, W is the width in mm, T is the thickness in mm, D_g is the geometric mean diameter in mm and D_a is the arithmetic mean diameter of pineapple fruit.

Determination of Surface Area

Surface area (SA) was theoretically calculated as apparent surface area using equations given by Lorestani 92012), Shahbazi.& Rahmati (2013) and Panda et al.(2020). The surface area of each pineapple fruit was calculated based on the geometric mean diameter (D_g) using the following Equation (3.3).

$$SA = \pi(D_g)^2 \quad (3)$$

Where SA is surface area in mm^2, and D_g is the geometric mean diameter in mm.

Determination of Mass

Five samples of whole pineapple fruits were weighed individually by using the analytical balance (TX3202L, Shimadzu, Kyoto, Japan) with an accuracy of 0.01g. The weight was measured in grams (g).

Determination of Volume

The water displacement method was used to measure the volume of the pineapple fruits (Abdul Halim, 2021). The container with a volume of 5 litres was filled with 4.4 litres of water and the initial volume was recorded. The displaced water when the fruit was placed in the container is recorded as the volume of the sample.

Determination of Sphericity

Sphericity (∅) is defined as the ratio of the surface area of a sphere having the same volume as the fruit to the surface area of the fruit (Dhineshkumar & Siddharth, 2015). The shape of a food material is usually expressed in terms of its sphericity. The sphericity of each pineapple fruit was calculated based on Equation (4) given by Bhore et al. (2015), Azman et al. (2020), and Birania et al. (2022).

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (4)$$

Where L is the length in mm, W is the width in mm (diameter), and T is the thickness in mm.

Determination of Aspect Ratio

The aspect ratio (R_a) was obtained using the following relationship Equation (5) as recommended by Azman et al. (2020) and Birania et al. (2022).

$$R_a = \frac{W}{L} \quad (5)$$

Where R_a is the aspect ratio, L is the length in mm, and W is the width in mm.

Determination of Projected Area

The following formulas equations (6), (7), (8), and (9) were used with perpendicular directions to determine the projected areas of pineapple fruits and the criteria projected area (CPA)), suggested by Azman et al. (2022) and Panda et al. (2020).

$$PA_L = \frac{\pi LW}{4} \quad (6)$$

$$PA_T = \frac{\pi TW}{4} \quad (7)$$

$$PA_W = \frac{\pi WW}{4} \quad (8)$$

$$CPA = \frac{PA_L + PA_T + PA_W}{3} \quad (9)$$

Mass Modelling

To estimate the mass, M of pineapple fruits Linear, Quadratic, S-curve, and Power were used and fitted with the data from the trials. These models are presented in Equations (10), (11), (12) and (13) respectively (Shahbazi & Rahmati, 2012; Azman et al., 2020):

$$M = a + bX \quad (10)$$

$$M = a + bX + cX^2 \quad (11)$$

$$M = a + \frac{b}{X} \quad (12)$$

$$M = aX^b \quad (13)$$

where X = the value of an independent parameter, in order to determine how it relates to mass; a, b, and c = curve fitting parameters which are different in each equation.

Statistical Analysis

Employing statistical tools SigmaPlot (Version 18.0), data analysis and mass modelling prediction were carried out. Standard error of the estimate (SEE) and coefficient of determination (R^2) were chosen as the conditions to assess the efficacy of regression models. The models that were appropriate were those with greater R^2 and lower SEE values. In general, for regression equations, the R^2 value near 1.00 shows a good fit with the model (Shahbazi & Rahmati, 2012).

Result and Discussion

Dimension and Shape

Table 1 shows that the average L of pineapple fruits was 217.8 mm, with a range of 193.0 to 240.0 mm. The average D and T of a pineapple fruit, however, were 132.7 mm and 132.9 mm, respectively. The numbers for maximum and minimum W were 143.0 mm and 114.0 mm, respectively, whereas the values for maximum and minimum T were 142.0 mm and 116.0 mm, respectively As can be seen, the pineapple fruits' mean L had the highest values when compared to thickness and width. The average thickness and width values were almost identical at the same time. The reason for this is that pineapple fruits resemble pinecones in shape. The measurements' relative standard deviations for L, T, and W were 16.1 mm, 8.8 mm, and 9.8 mm, with Lhaving the highest standard deviation. Because there were only 5 samples of pineapple fruits utilised in the experiment, the standard deviation has a higher value. Circumference (D), which was also measured, had a mean value of 394.3±35 mm. The measurements of the circumference of pineapple fruits ranged from 307.0 mm to 432.0 mm. In a comparison of the 'MD2' variety with the other varieties of pineapple fruits, it can be said that the mean length of MD2 variety (217.8 mm) is larger than Josapine variety, which is 126.35mm (Shamsuddin et al., 2009). The same observation was also observed for the T and W, where the MD2 variety has a larger mean of T (132.7 mm) and W (132.9 mm) compared to the Giant Kew variety (95.6 mm) and (86.56 mm) respectively (Bhore et al., 2017).

Table 1. Physical properties of pineapple fruit variety MD2

Parameter	Mean	Standard deviation	Maximum Value	Minimum Value
L (mm)	217.8 ± 16.1	16.1	240.0	193.0
T (mm)	132.7 ± 8.8	8.8	142.0	116.0
W (mm)	132.9 ± 9.8	9.8	143.0	114.0
D_g (mm)	156.5 ± 8.7	8.7	169.5	138.1
D_a (mm)	161.2 ± 8.7	8.7	175.0	142.7
D (mm)	394.3 ± 35.0	35.0	432.0	307.0
AR	0.61 ± 0.06	0.06	0.72	0.51
m (g)	1730.4 ± 193.5	193.5	1996.1	1507.3
V (cm^3)	1420 ± 120.7	120.7	1600.0	1300.0
SA (mm^2)	77107.4 ± 8427.5	8427.5	90258.2	59927.3
Ø	0.72 ± 0.05	0.05	0.8	0.64
PA_L (mm^2)	22746.0 ± 2560.9	2560.9	26941.2	17540.04
PA_T (mm^2)	13910.0 ± 1849.2	1849.2	15940.2	10471.90
PA_W (mm^2)	13942.9 ± 1986.3	1986.3	16052.4	10201.86
CPA (mm^2)	16866.3 ± 1993.5	1993.5	19644.6	12767.24

Geometric Mean Diameter (Dg) and Arithmetic Mean Diameter (Da)

Based on Table 1, D_g of pineapple fruits was recorded as 156.5±8.7 mm. The maximum and minimum values of D_g were 169.5 mm and 138.1 mm respectively. Compared to the other variety of pineapple fruits such as the Giant Kew variety, pineapple fruits variety MD2 had a larger mean value of D_g, which was 156.5 mm compared to 102.6 mm for the Giant Kew variety (Bhore et al., 2017). The mean value of D_a of pineapple fruits was 161.2±8.7 mm. Da had values as high as 138.1 mm and as low as 169.6 mm, respectively. Designing sorting and packaging machinery can benefit from knowing the details of Dg and Da, especially for goods having asymmetrical geometrical shapes.

Surface area is expressed as the total area over the outside of a fruit. Based on Table 1, the mean value of the surface area of pineapple fruits variety MD2 was 77107.4±8427.5 mm^2. The maximum and minimum values of pineapple fruits' surface area were 90258.2 mm^2 and 59927.3 mm^2 respectively. Clayton et al. (1996) claimed that surface area is important when expressing the transfer of heat into or out of fruits and vegetables. Comparing the surface area of pineapple fruits with other fruits such as papaya fruit, pineapple fruit has a smaller surface area (77107.4 mm^2) than papaya fruit which has a surface area of 643.40 cm^2 or 164340 mm^2 (Khet et al., 2018). Thus, it can be concluded that the rate of energy transfer through the surface area of the pineapple fruit is much slower compared to the papaya fruit.

Mass

According to Table 4.1, the mean value of the mass of pineapple fruit was shown. The mean value for pineapple fruits' mass varied from 1507.3 g to 1996.1 g, with a mean value of 1730.4 g. The standard deviation for the mass of pineapple fruits was 8427.5 g. Siti Rashima et al. (2019) claimed that the mass of pineapple fruits of variety MD2 ranged from 1.5 kg to 3.0 kg, and that their discovery was consistent with the observed result.

However, nutritional aspects, crop load, water availability, as well as physiological aspects including seed weight, carbohydrate availability, and bloom quality, may affect the pineapple fruit's mass.

Table 4. Model validation for Quadratic model based on volume with a given volume.

Sample	Mass measured, m (g)	Volume measured, V (cm^3)	Estimated mass, m_e (g)	Error %
1	1996.03	1600.00	2011.32	0.77
2	1569.60	1300.00	1538.82	1.96
3	1893.07	1500.00	1873.82	1.02
4	1685.73	1400.00	1716.32	1.81
5	1507.30	1300.00	1538.82	2.09

Based on a study by Mohd Ali et al. (2020) that looked at the average weight of pineapple fruits for a number of different cultivars, including Smooth Cayenne, Sarawak, Hilo, Champaka, Kew, N36, Queen, Morris, Ripley, Mauritius, Alexandra, Yankee, Josapine, Mas Merah, Red Spanish, Gold, MD2, Perola, Pernambuco, Sugar Loaf, Perolera, and These kinds were divided into 7 categories, with the average mass of each group being 2-3kg, 0.8-1.5kg, 1-2kg, 1.5-3.0kg, 1-5kg, and 3-4kg, respectively. These groups were Cayenne, Queen, Spanish, Extra Sweet Cayenne Hybrids, Pernambuco, Modilonus, and Perolera. The MD2 variety's average mass ranges from 1.5 to 3.0kg because it is in Extra Sweet Cayenne Hybrids.

Volume

As tabulated in Table 1, the mean volume for pineapple fruits was recorded as 1420 cm^3 with a standard deviation of 120.7 cm^3. The volume varied from 1300 cm^3 to 1600 cm^3. Lapcharoensuk et al. (2017) studied the correlations of all physicochemical properties including volume and they found that weight correlated positively with volume. This showed that the weight and volume of pineapple fruit rose along with its size. Additionally, they claimed that depending on its ripeness, pineapple fruit volume fluctuates (Lapcharoensuk et al., 2017). When comparing the MD2 variety's volume (872 to 1200 cm^3) to that of the Smooth Cayenne variety, the MD2 variety is greater (1420 cm^3).

Sphericity

Sphericity is defined as the characteristic shape of a solid object relative to that of a sphere of the same volume. Sphericity is used to describe the shape of the pineapple where if the value of sphericity is close to 1, it can be considered an ideal sphere. Based on the result obtained, the mean value of the sphericity of pineapple fruits was 0.72±0.05. The maximum and minimum values of pineapple fruits were 0.64 to 0.80, respectively. Thus, from the mean value of sphericity, the pineapple fruits cannot be considered an ideal sphere because the sphericity value of pineapple fruits was smaller than one. A study conducted by Bhore et al. (2017) found that the sphericity of pineapple fruit was in the range between 0.65 and 0.85 with an average value of 0.77 at the standard deviation of ± 0.05. This finding was nearly the same as the result obtained.

Aspect Ratio

Aspect ratio, which compares the width to the length of the fruits in proportion, is one of the phrases used to describe the shape of a food material. The mean value of the aspect ratio of pineapple fruits is 0.61 with a standard deviation of 0.06. The minimum and maximum values of the aspect ratio of pineapple fruits were 0.72 and 0.51 respectively, as shown in Table 1. This high aspect ratio suggested that rather than rolling like gram, pineapple fruits will slide along their flat surface like oil bean seeds. The design of hoppers must take into account this propensity to roll or slide (Dash et al., 2008). However, there is no information from the previous research about the aspect ratio of pineapple fruit. From previous research, the aspect ratio for Ipoli fruits was found to be 0.7 (Burubai, 2014) while dabai fruits were found to be 0.56 (Abdul Halim, 2021).

Projected Areas

Based on Table 1, the mean value for other measured physical properties was projected area perpendicular to the length (PA_L), projected area perpendicular to the thickness (PA_T), projected area perpendicular directions to the width (PA_W), and criteria projected area (CPA) of pineapple fruits were 22746.0 ± 2560.9 mm^2, 13910.0 ± 1849.2 mm^2, 13942.9 ± 1986.3 mm^2, 16866.3 ± 1993.5 mm^2, respectively. The minimum and maximum values of PA_L were 17540.0 mm^2 and 26941.2 mm^2, while for PA_T, the minimum and maximum values were 10471.9 mm^2 and 15940.2 mm^2. Other than that, the minimum and maximum values of PA_W were 10201.9 mm^2 and 16052.5 mm^2. The minimum and maximum values of CPA were 12767.2 mm^2 and 19644.6 mm^2 respectively. Projected area values play a significant role in machine vision-based grading system design and development. To predict the ideal time to harvest, the amount of water lost, and the amount of heat and mass transferred during drying and cooling, the projected area can be used to determine the respiration rate, maturity index, and gas permeability. Additionally, the natural diversity in fruit dimensional qualities may be the cause of the projected disparity in the physical properties (Azman et al., 2020).

Mass Modelling

In mass modelling, the dimensions, geometric mean diameter, arithmetic mean diameter, volumes, surface areas, and projected areas in three perpendicular directions of pineapple fruits were used. Table 2 showed the best models for predicting mass using the mean dimensions, weight, surface areas, projected area and volume of pineapple fruits along with their coefficients of determination, R^2, and SEE. Using the coefficient of determination (R^2), the regression mass was assessed, and the best-fit model was identified by a higher R^2 value.

Table 2. Mass models of pineapple fruits based on physical properties L, T, W, D_g, D_a and D

Dependent parameter	Independent parameter	Model equation	Regression constant			Statistical parameter		The best fitted model
			a	b	c	R^2	SEE	
M (g)	L (mm)	Linear	-772.634	11.492	-	0.915	58.493	Quadratic
M (g)	L (mm)	Quadratic	5536.354	-46.936	0.135	0.937	52.550	
M (g)	L (mm)	S-curve	4174.550	-529603.009	-	0.894	65.294	
M (g)	L (mm)	Power	0.653	1.464	-	0.919	57.181	
M (g)	T (mm)	Linear	-863.930	19.727	-	0.831	86.936	Quadratic
M (g)	T (mm)	Quadratic	19874.523	-303.408	1.252	0.954	47.663	
M (g)	T (mm)	S-curve	4173.446	-319584.668	-	0.800	94.600	
M (g)	T (mm)	Power	0.908	1.548	-	0.839	84.876	
M (g)	W (mm)	Linear	-1476.855	23.956	-	0.806	88.422	Quadratic
M (g)	W (mm)	Quadratic	22153.119	-335.620	1.363	0.940	52.030	
M (g)	W (mm)	S-curve	4754.771	-403419.002	-	0.768	96.734	
M (g)	W (mm)	Power	0.125	1.946	-	0.822	84.694	
M (g)	D_g (mm)	Linear	-1999.495	23.739	-	0.835	80.495	Quadratic
M (g)	D_g (mm)	Quadratic	8750.875	-113.506	0.437	0.857	78.356	
M (g)	D_g (mm)	S-curve	5394.705	-574512.893	-	0.816	84.915	
M (g)	D_g (mm)	Power	0.141	1.863	-	0.804	88.866	
M (g)	D_a (mm)	Linear	-1529.034	423.379	-	0.821	85.053	Quadratic
M (g)	D_a (mm)	Quadratic	9333.968	-116.006	0.426	0.865	76.926	
M (g)	D_a (mm)	S-curve	4854.465	-502084.419	-	0.789	92.263	
M (g)	D_a (mm)	Power	0.090	1.940	-	0.832	82.328	
M (g)	D (mm)	Linear	-976.008	6.796	-	0.881	68.374	Quadratic
M (g)	D (mm)	Quadratic	15537.922	-77.207	0.106	0.935	48.706	
M (g)	D (mm)	S-curve	4350.654	-1038940.164	-	0.859	74.387	
M (g)	D (mm)	Power	0.123	1.595	-	0.887	66.654	

Models Based on Dimensions

Table 2 shows the mass prediction results of the pineapple fruits based on the L, T, W, D_g and D_a. It shown that, for all features specified on dimensions, the Quadratic model was the best-fit model to determine and assess the mass of pineapple fruits (length, thickness, width, circumference, Dg, and Da). For pineapple fruits, T had the highest value of R^2 and the lowest value of SEE, which were 0.9539 and 47.663, respectively, as shown in Table 2. Highest value of coefficient determination (R^2) showed that a respectable percentage of the variability in the dependent variable is explained by the model (Azman et al., 2020), while lower standard error estimate (SEE) indicated that the approximate size of the prediction errors (Siegel & Wagner, 2022).The lower the SEE value, smaller the prediction error and more accurate the fitted model. Equation (41) displays the equation of the Quadratic model found based on physical properties thickness (T).

$$M = 19874.523 - 303.408\,T + 1.252\,T^2 \quad (14)$$

According to Table 2, the best fit model for mass prediction of pineapple fruits based on the length (L) was quadratic model with highest R^2 of 0.9368 and lowest SEE of 52.55, followed by Power model with R^2 of 0.9189, Linear model with R^2 of 0.9151 and lastly S-curve model with R^2 of 0.8942. The SEE values for Power model Linear model and S-curve model were 57.181, 58.493 and 65.294, respectively. The best model for mass determination based on L was a Quadratic model following Equations (15)

$$M = 5536.354 - 46.936L + 0.135\,L^2 \quad (15)$$

A study conducted by Nur Salihah et al. (2015), suggested the best model for mass determination based on L for pomelo fruit was a Quadratic model which was similar to the findings. A similar model for onion and pepper berries in another study was suggested and reported by Ghabel et al. (2010) and Azman et al. (2020), where the best model for mass determination based on L was a Quadratic model.

Table 2. Mass models of pineapple fruits based on L, T, W, D_g, D_a and D

Dependent parameter	Independent parameter	Model equation	Regression constant			Statistical parameter		The best fitted model
			a	**b**	**c**	**R^2**	**SEE**	
M (g)	L (mm)	Linear	-772.634	11.492	-	0.915	58.493	Quadratic
M (g)	L (mm)	Quadratic	5536.354	-46.936	0.135	**0.937**	**52.550**	
M (g)	L (mm)	S-curve	4174.550	-529603.009	-	0.894	65.294	
M (g)	L (mm)	Power	0.653	1.464	-	0.919	57.181	
M (g)	T (mm)	Linear	-863.930	19.727	-	0.831	86.936	Quadratic
M (g)	T (mm)	Quadratic	19874.523	-303.408	1.252	**0.954**	**47.663**	
M (g)	T (mm)	S-curve	4173.446	-319584.668	-	0.800	94.600	
M (g)	T (mm)	Power	0.908	1.548	-	0.839	84.876	
M (g)	W (mm)	Linear	-1476.855	23.956	-	0.806	88.422	Quadratic
M (g)	W (mm)	Quadratic	22153.119	-335.620	1.363	**0.940**	**52.030**	
M (g)	W (mm)	S-curve	4754.771	-403419.002	-	0.768	96.734	
M (g)	W (mm)	Power	0.125	1.946	-	0.822	84.694	
M (g)	D_g (mm)	Linear	-1999.495	23.739	-	0.835	80.495	Quadratic
M (g)	D_g (mm)	Quadratic	8750.875	-113.506	0.437	**0.857**	**78.356**	
M (g)	D_g (mm)	S-curve	5394.705	-574512.893	-	0.816	84.915	
M (g)	D_g (mm)	Power	0.141	1.863	-	0.804	88.866	
M (g)	D_a (mm)	Linear	-1529.034	423.379	-	0.821	85.053	Quadratic
M (g)	D_a (mm)	Quadratic	9333.968	-116.006	0.426	**0.865**	**76.926**	
M (g)	D_a (mm)	S-curve	4854.465	-502084.419	-	0.789	92.263	
M (g)	D_a (mm)	Power	0.090	1.940	-	0.832	82.328	
M (g)	D (mm)	Linear	-976.008	6.796	-	0.881	68.374	Quadratic
M (g)	D (mm)	Quadratic	15537.922	-77.207	0.106	**0.935**	**48.706**	
M (g)	D (mm)	S-curve	4350.654	-1038940.164	-	0.859	74.387	
M (g)	D (mm)	Power	0.123	1.595	-	0.887	66.654	

For mass prediction of pineapple fruits based on width (W), the quadratic model has the highest R^2 of 0.940 and the lowest SEE of 52.030 compared to the Linear (R^2 = 0.806), S-curve (R^2 = 0.768), Power (R_2 = 0.822) model. The equation of quadratic model obtained showed in Equation (16).

$$M = 22153.119 - 335.620\,W + 1.363\,W^2 \quad (16)$$

For mass prediction of pineapple fruits based on D_g and D_a, the quadratic model was the best fit model which had the highest R^2 of 0.857 and the lowest SEE of 78.356 for D_g, and highest R^2 of 0.865 and the lowest SEE of 76.926 for D_a compared to the other model as in Table 2. The equation of quadratic model obtained to predict the mass of pineapple fruits based on D_g and D_a showed in Equation (17) and (18) respectively.

$$M = 8750.875 - 113.506\, D_g + 0.437\, D_g^2 \quad (17)$$

$$M = 9333.968 - 116.06\, D_a + 0.426\, D_a^2 \quad (18)$$

According to Table 2, the pineapple fruits had circumference (D) values with the highest R^2 (0.935) and the lowest SEE (48.706). The model equation obtained for these parameters was Quadratic. Equations (19) were determined for the parameters D.

$$M = 15537.922 - 77.207\, D + 0.106\, D^2 \quad (19)$$

As for the entire dimensions, the S-curve model was reported to have lower R^2 values except for D_g parameter, which had lower R^2 value for Power model. The lower R^2 values might be caused by the pineapple fruits' non-uniform mass corresponding to their size. Therefore, it is recommended to size pineapple fruits according to their length as suggested by Nur Salihah et. al [25], Ghabel. [26] and Azman [14].

Models Based on Volume

Based on Table 3, it showed the mass prediction results of the pineapple fruits based on actual volume (V), the Quadratic model and S-curve model based on V was found to be the best fit when compared to the other models. They had the similar and highest R^2 which was 0.981 and the lowest SEE of 28.840 (Quadratic model) and 28.038 (S-curve model). S-curve model was chosen as the best fitted model because it had highest R^2 and lowest SEE compared to Quadratic model. This finding was differed from previous study conducted by Nur Salihah et al., (2015), who found the Quadratic model was the best model

Table 3. Mass models of pineapple fruits based on volume, surface area and projected area

Dependent parameter	Independent parameter	Model equation	Regression constant			Statistical parameter		The best fitted model
			a	b	c	R^2	SEE	
M (g)	V (cm^3)	Linear	-520.534	1.585	-	0.978	29.567	S-curve
M (g)	V (cm3)	Quadratic	-2588.677	4.475	-0.001	0.981	28.840	
M (g)	V (cm^3)	S-curve	4039.966	-3258111.845	-	**0.981**	**28.038**	
M (g)	V (cm^3)	Power	0.144	1.294	-	0.977	30.178	
M (g)	SA (mm^2)	Linear	141.028	0.021	-	0.806	88.364	Quadratic
M (g)	SA (mm^2)	Quadratic	3206.432	-0.062	5.4E-07	**0.861**	**77.803**	
M (g)	SA (mm^2)	S-curve	3146.330	-107890514.3584	-	0.734	103.553	
M (g)	SA (mm^2)	Power	0.049	0.932	-	0.804	88.870	
M (g)	PA_L (mm^2)	Linear	168.048	0.069	-	0.827	83.571	Quadratic
M (g)	PA_L (mm^2)	Quadratic	2018.558	-0.097	3.66E-06	**0.850**	**81.076**	
M (g)	PA_L (mm^2)	S-curve	3171.832	-32388213.738	-	0.764	97.527	
M (g)	PA_L (mm^2)	Power	0.185	0.912	-	0.825	84.044	
M (g)	PA_T (mm^2)	Linear	-757.736	0.173	-	0.831	75.526	Quadratic
M (g)	PA_T (mm^2)	Quadratic	9810.755	-1.293	5.06E-05	**0.866**	**70.759**	
M (g)	PA_T (mm^2)	S-curve	4213.347	-35567762.670	-	0.812	79.601	
M (g)	PA_T (mm^2)	Power	0.003	1.393	-	0.833	74.996	
M (g)	PA_W (mm^2)	Linear	-490.851	0.154	-	0.845	72.388	Quadratic
M (g)	PA_W (mm^2)	Quadratic	11070.146	-1.456	5.57E-05	**0.912**	**57.429**	
M (g)	PA_W (mm^2)	S-curve	3911.703	-31279492.453	-	0.817	78.515	
M (g)	PA_W (mm^2)	Power	0.007	1.301	-	0.848	71.512	
M (g)	CPA (mm^2)	Linear	-347.108	0.121	-	0.852	74.091	Quadratic
M (g)	CPA (mm^2)	Quadratic	2692.564	-0.234	1.03E-05	**0.868**	**73.488**	
M (g)	CPA (mm^2)	S-curve	3759.205	-34558470.684	-	0.822	81.423	
M (g)	CPA (mm^2)	Power	0.013	1.212	-	0.855	73.537	

for Malaysian variety of pomelo fruit. The same result also reported by Azman et al. (2020). The Power model was found to have the lowest R^2 (0.977) compared to the other models.

$$M = -2588.677 + 4.475\,V - 0.001\,V^2 \quad (20)$$

$$M = 4039.966 - \frac{3258111.845}{V} \quad (21)$$

Models Based on Surface Area

Table 3 showed the results of mass prediction of pineapple fruits based on surface area (SA). The Quadratic model was the best fit based on the highest value of R^2 compared to the other models. The values of R^2 and SEE for Quadratic model were 0.861 and 77.803, respectively. The equation of Quadratic model obtained showed in Equation (22).

$$M = 3206.432 - 0.062\,SA + 5.4E - 07\,SA^2 \quad (22)$$

Linear model had the highest R^2 (0.806) after Quadratic model followed by Power model with R^2 of 0.804 and lastly S-curve model, which had the lowest R^2 (0.734) and highest SEE value of 103.553. Therefore, the Quadratic form was shown as the suggested mass model.

Models Based on Projected Area

Among the models based on the projected area were PA_L, PA_T, PA_W, and CPA. Table 3 showed the results of mass prediction of pineapple fruits based on projected area PA_L, PA_T, PA_W, and CPA. It was found that the best fit model for PA_L, PA_T, PA_W, and CPA were quadratic model based on the highest values of R^2 and lowest values of SEE. The Quadratic model comprising PA_L was the best fit with the highest R^2 of 0.85 and lowest SEE of 81.076. While the Quadratic model comprising, PA_T was the best fit with the highest R^2 0.866 and lowest SEE of 70.759 as shown in Table 4.3. The Quadratic model based on PA_W also achieved with the highest R^2 of 0.912 and lowest SEE of 57.429. While for criteria projected area (CPA), the Quadratic model was the best fit with the highest R^2 of 0.868 and lowest SEE of 73.488 compared to models. The equation of Quadratic model based on PA_L, PA_T, PA_W, and CPA obtained to predict mass of pineapple fruits were showed in Equation (23), (24), (25), (26) respectively.

$$M = 2018.558 - 0.097\,PA_L + 3.66 \times 10^{-6}\,PA_L^2 \quad (23)$$

$$M = 9810.755 - 1.293\,PA_T + 5.06 \times 10^{-5}\,PA_T^2 \quad (24)$$

$$M = 11070.146 - 1.456 + 5.57\,PA_W \times 10^{-5} PA_W^2 \quad (25)$$

$$M = 2692.564 - 0.234\,CPA + 1.03 \times 10^{-5}\,CPA^2 \quad (26)$$

In addition, the Quadratic model of projected area perpendicular to the width (PA_W) shown in Table 3 was preferred as the best model to calculate the mass of pineapple fruits. This was due to the high R^2 value of 0.912 compared to PA_L (0.85), PA_T (0.866) and CPA (0.868). All three projected areas are necessary to be specified and applied in grading the pineapple fruits by using this model.

Model Validation

From previous section, it was found that the recommended mass model is based on the volume which had the highest value of determination coefficient (R^2). The equation 4.7 and 4.8 showed the equation that can be used to predict the mass of pineapple fruits. Model validation is needed in order to determine the validation of the model. To determine the validation of the mass model based on the volume, the physical properties which is volume is needed. The percentage of error is calculated to determine the validity of the model. Equation 27 is used to calculate the percentage of errors:

$$\text{Percentage of errors} = \frac{|\text{Estimated mass} - \text{Measured mass}|}{\text{Measured mass}} \times 100\% \tag{27}$$

Table 4 and 5 shows model validation for Quadratic model and S-curve model based on volume with given volume. Based on Table 4 and 5, can be observed that the percentage of error for both model when predict the mass of pineapple fruits is below 10 percent. According to Seyedpoor, S. (2014), the appropriate error percentage must be below 10%. Thus, it can be concluded that the mass model based on the volume is valid and can be used to predict the mass of pineapple fruits.

Table 4. Model validation for Quadratic model based on volume with a given volume.

Sample	Mass measured, m (g)	Volume measured, V (cm^3)	Estimated mass, m_e (g)	Error %
1	1996.03	1600.00	2011.32	0.77
2	1569.60	1300.00	1538.82	1.96
3	1893.07	1500.00	1873.82	1.02
4	1685.73	1400.00	1716.32	1.81
5	1507.30	1300.00	1538.82	2.09

Table 5. Model validation for S-curve model based on volume with a given volume.

Sample	Mass measured, m (g)	Volume measured, V (cm^3)	Estimated mass, m_e (g)	Error %
1	1996.03	1600.00	2003.65	0.38
2	1569.60	1300.00	1533.73	2.29
3	1893.07	1500.00	1867.89	1.33
4	1685.73	1400.00	1712.74	1.60
5	1507.30	1300.00	1533.73	1.75

Conclusion

The physical properties for dimension of pineapple fruits such as L, T, W, D_g, D_a and circumference were found to be 217.8mm, 132.7mm, 132.9mm, 156.5mm, 161.2mm, 394.3mm respectively. Meanwhile for aspect ratio, mass, volume, surface area, sphericity, PA_L, PA_T, and PA_W were found to be 0.61, 1730.4g, 1420 cm^3, 77107.4 mm^2, 0.72, 22746.0 mm^2, 13942.9 mm^2, and 16866.3 mm^2 respectively. The Quadratic model is best fitted with all physical properties due to its economical viewpoint excluding for actual volume which best fit with Quadratic and S-curve model.

Recommendations

The mass model of pineapple fruits based on actual volume in the obtained results is recommended for designing and optimizing machines for handling, cleaning, conveying, and storing.

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Author Information

Rosnah Shamsudin
Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
Contact e-mail: *rosnahs@upm.edu.my*

Hasfalina Che Man
Department of Biological and Agricultural, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Siti Hajar Ariffin
Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Siti Nor Afiekah Mohd Ghani
Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Nazatul Shima Azmi
Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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