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Some physical properties and relationship between fractions of dabai fruit (*Canarium Odontophyllum Miq.*) variety '*Ngemah*'

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Abstract

Some physical properties of different fractions part of dabai fruit were determined for useful application in appropriate mathematical models for the process optimization and designing processing equipment. The objective of this study was to determine and compare some physical properties of three different fractions (whole, kernel and nut) by measuring the dabai fruit. Based on the result, the whole fruit reported the highest value in terms of length (L) (39.14 mm), thickness (T) (22.76 mm), geometric mean diameter (D_g) (26.86 mm), arithmetic mean diameter (D_a) (27.89mm), surface area (2269.80 mm^2), mass (12.38 g), volume (11300 mm^3), sphericity (68.67%), and aspect ratio (Ra) (55.69%). On the other hand, the true density, bulk density, and porosity, the nut fraction has the highest values with 2755.0 kg/m^3, 738.180 kg/m^3 and 71.44%, respectively. Based on principal component analysis (PCA), the first principal component has a large positive association with L, T, W, mass, Ra, D_g, D_a and surface area. Meanwhile, there is a large negative association with true density and porosity for the second component analysis.

1. Introduction

Dabai (*Canarium Odontophyllum Miq.*) is a Burseraceae fruit found predominantly in Asia, Africa, and the Pacific Islands, with over 100 species estimated (Weeks *et al*., 2005; Chua *et al*., 2015). It is most commonly referred to as dabai in Malaysia, and it is one of the most underutilised products, notably in Sarawak's Sibu and Kapit regions (Chua *et al*., 2015). Sarawak is a state on Borneo Island with an abundance of underutilised green crops that grow naturally in the territory of the 'Iban' community.

Dabai has three main fruit fractions that make up the whole fruit with purple dark skin and yellow pulp. The interior side of the fruit contains a single three-angled seed known as the nut after the skin and pulp have been removed. The dabai fruit's nut has a hard shell and is sub-triangular in shape. The kernel is contained within the nut, and it is said to have an almond taste and flavour (Azlan *et al*., 2009). However, there are only a few research reports that support this argument. On the contrary, dabai fruit is commonly consumed for its outer purple skin and light yellow fleshy pulp, but the seed is usually discarded (Chew *et al*., 2012). The fruit is often blanched in hot water for 3–5 mins to make the flesh creamier and softer before serving as a snack or side dish seasoned with sugar, salt, pepper, or sauce.

The physical properties of each of the fruit fractions must be identified in order to develop technologies for the harvesting, processing, transportation, sorting, and separation of the dabai fruit, nut and kernel. This is because determining the physical qualities of food is critical for process design and operation, as well as predicting food response to processing, distribution, and storage conditions (Azman *et al.*, 2020). Physical properties of fruit are vital for determining a fruit's unique and typical manner of reacting to physical treatments that occur frequently in the actual world of food processing, including mechanical, thermal, electrical, optical, acoustic and electromagnetic processes (Wilhelm *et al.*, 2013). The important parameters of physical properties that are often studied are the shape of the fruit, size, density, porosity, volume,

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weight and surface area of the fruit. There is a dearth of information or research on the physical properties of dabai fruit, particularly the fractions of the fruit that are the whole fruit, the nut, and the kernel, which underlines the goal of this research.

The objective of this research was to determine the physical properties of different fractions of the '*Ngemah*' variety dabai in terms of its whole fruit, the nut, and the kernel and to understand its correlation.

2. Materials and methods

2.1 Raw materials

Dabai fruits of *Ngemah* variety were obtained from dabai fruit supplier in Sibu, Sarawak, Malaysia. It was packed in an icebox and transported on the same day to Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The fruits were stored in the freezer (SJC218, Sharp, Malaysia) at a temperature of -4°C. Fruits that were free from damages and pests were chosen for the physical properties of different fractions of the dabai variety '*Ngemah*'. Fifty defrosted Dabai fruit samples were chosen randomly and measured for the physical properties of different fruit fractions.

2.2 Determination of dimension and shape of fractions of Dabai fruit

The measurements of the length, width and thickness of the whole fruit, nut and kernel of dabai were done according to Figure 1(a-c). The length (mm), width (mm), and thickness (mm) of each fraction of fruits were measured using a vernier calliper.

2.3 Determination of geometric mean diameter (D_g) and arithmetic mean diameter (D_a)

The geometric mean diameter (D_g) and arithmetic mean diameter (D_a) of each fruit fraction were calculated using the values of the length (L), thickness (T), and width (W) obtained using the vernier calliper. The geometric mean diameter was described in equation (1), and the arithmetic mean diameter formula was described in equation (2) according to a method by (Ehiem *et al.*, 2016).

$$Dg = \sqrt[3]{LTW} \quad (1)$$

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

2.4 Determination of surface area

The surface area, SA in m^2 of each fraction of fruit was calculated using Equation (3) (Sirisomboon *et al.*, 2007) where the value of geometric mean diameter was used.

$$SA = \Pi Dg^2 \quad (3)$$

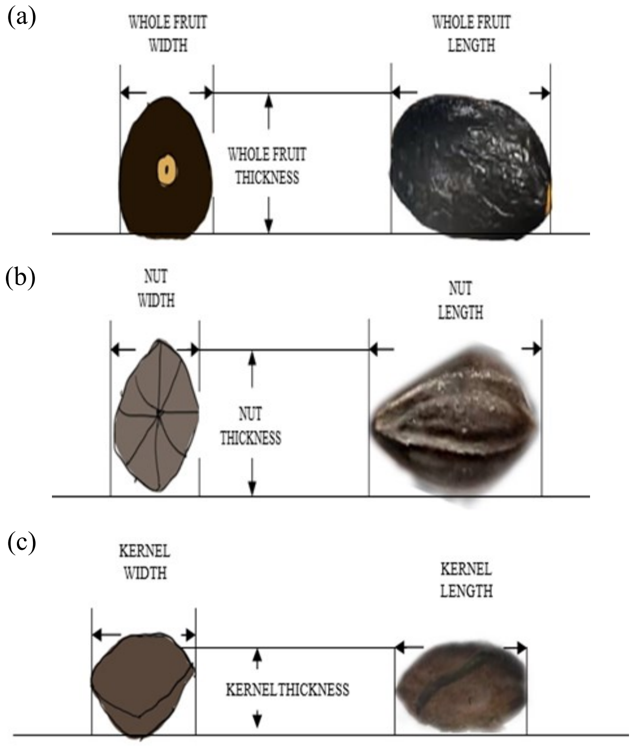

Figure 1. Dimensions of (a) whole fruit, (b) nut, (c) kernel of Dabai fruit *'Ngemah'* variety.

2.5 Determination of mass

The dabai fruit samples were weighed using the analytical balance (ME204E, Mettler Toledo, USA) with accuracy of 0.01 g.

2.6 Determination of volume

The volume of the fruit fractions was measured using the water displacement method where each sample was placed in a beaker filled with water where the initial volume was recorded (Khoshnam *et al.*, 2007). The displaced water is recorded as the volume of the sample.

2.7 Determination of sphericity

The sphericity (Ø) of the fruit fractions were calculated using the dimensions measured as follows in equation (4) (Sirisomboon *et al.*, 2007).

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

2.8 Determination of bulk density

Bulk density was measured as the ratio of the mass samples to the volume of the container filled in. For the whole fruit, the volume of container used is 500 cm^3, 250 cm^3 for the nut of dabai fruit, and 100 cm^3 for the kernel of dabai fruit. The bulk density was calculated by using the formula in Equation (5) (Ehiem *et al.*, 2016).

$$p_b = \frac{M_p}{V_c} \quad (5)$$

Where M_p stands for the mass of the sample in g and

V_c is the volume of the container in cm^3.

2.9 Determination of true density

The true density of the samples was calculated using the formula is in Equation (6) (Mirzabe *et al.*, 2013) :

$$\rho T = \frac{m}{V} \quad (6)$$

Where m is the mass of sample in g and V is the volume of sample in ml measured using the water displacement method.

2.10 Determination of porosity

The value of bulk density and true density were used in the calculation of porosity (ε). The formula is in Equation (7) (Mirzabe *et al.,* 2013).

$$\varepsilon = \left(1 - \frac{p_b}{\rho T}\right) \times 100 \quad (7)$$

Where, ρ_b is bulk density in (g/cm_3) and ρ_T is true density in (g/ml). The result is expressed as percentage (%).

2.11 Determination of angle of repose

The angle of repose was measured using the hollow cylinder method where the samples were placed in a hollow cylinder that was in contact with the base (Zhichao, 2011). The angle of repose is then calculated using the arctan rule by measuring the height and radius of the pile. The formula to calculate the angle of repose is in Equation (8) (Burubai and Amber, 2014):

$$\theta = tan^{-1}\frac{2H}{D} \quad (8)$$

Where H stands for the height of the pile and D is the diameter of the pile formed.

2.12 Determination of aspect ratio

The sphericity (R_a) of the fruit fractions was calculated using Equation (9) (Burubai and Amber, 2014).

$$Ra = \frac{W}{L} \times 100 \quad (9)$$

2.12 Principal component analysis

Principal component analysis (PCA) was carried out by evaluating the relationships among the variables of parameters of the three fruit fractions: whole, nut, and kernel of dabai fruit. The mean of the 50 samples of each fruit fraction was used (Milošević *et al*., 2014). For determining the number of principal components, the size of the eigenvalues used were the largest eigenvalues, as referred to retain the principal components. Principal components that have eigenvalues of more than 1 were used according to the Kaiser criterion. Kaiser's criterion is to remove all the components that have eigenvalues under 1.0.

2.13 Statistical analysis

Analysis of variance (ANOVA) was carried out in 50 samples of each fraction where the data was expressed as mean±SD. The differences in analysis of variance (ANOVA) were judged by the significance at the $p<0.05$ level. Pearson's correlation coefficient is used to find the correlation between the parameters of the whole fruit, nut and kernel of dabai fruit (Valentini *et al.*, 2015). These analyses were carried out in Minitab 12.0 (Pennsylvania, USA, 2019).

3. Results and discussion

3.1 Dabai fruit fractions dimension

The dimension of the fractions of fruit was determined using length (mm), thickness (mm) and width (mm). Based on Table 1, the average value of length, thickness, and width for the whole fruit of dabai fruits was 39.140 mm, 22.76 mm, and 21.78 mm respectively. As for the nut of dabai fruit, the data obtained were 34.48 mm, 17.38 mm and 16.59 mm for length, thickness and width, respectively. The kernel dimensions for length, thickness, and width are 23.21 mm, 12.17 mm, and 7.08 mm. In comparison, the length of the whole fruit is the longest at 39.140 mm followed by the nut of the fruit with values of 34.48 mm and 23.21 mm for the kernel fraction. Furthermore, the whole fruit also is the highest for the thickness parameter with 22.76 mm, followed by 17.38 mm for the nut fraction and 12.17 mm for the kernel fraction. Finally, the width of the whole fruit is the longest at 21.78 mm followed by 16.59 mm for nut and 7.08 mm for dabai kernel.

The lengths of all the fruit fractions differ significantly ($P < 0.05$) from one another, as do their thickness and width, demonstrating that each fraction of a dabai fruit has a different dimension. The whole fruit is 13.50% longer than the nut fraction in length. Furthermore, the nut fraction is 18.57% longer than the kernel fraction. The thickness and width parameters show the same trend for the different fractions. The thickness of the whole fruit is 23.65% more than the thickness of the nut and 46.54% more than the thickness of the kernel. As for the width parameter, the whole fruit is 23.82% higher than the nut fraction and 67.487% higher than the width of the kernel. Because the flesh of the dabai fruit accounts for 54 to 60% of the weight of the fruit, removing the flesh to extract the nut of the dabai fruit will also alter the dimension of the fruit fraction (Ariffin *et al*., 2020). It can also be used to describe the kernel dimension, which is enclosed in the nut's hard shell. The elimination of the hard outer

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Table 1. The physical properties of the fruit fractions of 'Ngemah' variety Dabai fruit.

Properties	Fruit Fractions		
	Whole Fruit	Nut	Kernel
Length (mm)	39.14±1.63[a]	34.48±1.47[b]	23.21±2.42[b]
Thickness (mm)	22.76±1.31[a]	17.38±1.20[b]	12.17±0.87[c]
Width (mm)	21.78±0.98[a]	16.59±0.94[b]	7.08±0.64[c]
Dg	26.86±1.06[a]	21.49±1.01[b]	12.72±0.69[c]
Da	27.89±1.05[c]	22.81±1.00[a]	14.02±7.00[b]
Surface area (mm^2) (ellipsoid)	2269.80±181.1[a]	1454.40±139.70[b]	509.80±56.25[c]
Mass (g)	12.38±1.57[a]	5.19±0.75[b]	0.99±0.18[c]
Volume (mm^3)	11300±2215[a]	2040±637.60[b]	1000±0.00[c]
Sphericity (%)	68.67±2.32[a]	62.35±2.12[b]	55.13±4.67[c]
True Density (kg/m^3)	1112.00±119.40[b]	2755±804[a]	990.80±184.30[b]
Bulk Density (kg/m^3)	717.60±26.80[b]	738.18 ±19.62[a]	640.28±11.83[c]
Porosity (%)	34.77±7.05[b]	71.44±6.50[a]	33.30±11.59[b]
Aspect ratio (%)	55.695±2.744[a]	48.135±2.362[b]	30.842±4.274[c]

Values are presented as mean±standard error of 50 samples of each fruit fraction. Values with different superscripts within the same row are statistically significantly different (P<0.05) by Tukey's HSD test.

shell resulted in a reduced kernel fraction dimension.

When comparing the whole fruit length of the '*Ngemah*' variety to the other dabai varieties, it can be stated that the whole fruit length of the *Ngemah* variety (39.14 mm) is almost the same as *Bujur*, which is 3.98 cm or 39.80 mm (Chua *et al*., 2015). Furthermore, the whole fruit width of the *Ngemah* variety (21.780 mm) is approximately identical to that of *Biasa* (2.10 cm or 21.00 mm). Unfortunately, regarding the nut and kernel portion dimensions, there is less information about other varieties of dabai.

3.2 Geometric mean diameter (Dg) and arithmetic mean diameter (Da)

Dabai fruit fractions had a significant difference in geometric mean diameter (Dg) and arithmetic mean diameter (Da) ($p < 0.05$). The average value of the Dg of the fruit fractions in Table 1 shows that the whole fruit achieves the highest average value with 26.86 mm, followed by the nut and kernel of fruit with 21.49 mm and 12.72 mm, respectively. The average value of Da of the fruit fractions shows a similar trend result where the whole fruit has the highest average value, followed by the nut and the kernel with values of 27.89 mm, 22.82 mm and 14.02 mm, respectively.

The whole fruit, nuts, and kernel fractions of *Jatropha curcas* L., or physic nut, have Dg values of 31.600 mm, 13.400 mm and 10.550 mm, respectively (Sirisomboon *et al*., 2007). When comparing the Dg of dabai with physic fruit, the Dg of dabai's whole fruit is 15% lower than the physic nut. The nut and kernel fraction of dabai have a higher value of D_g than the nut (37.65%) and kernel (17.06%) fraction of physical nut. It can be determined that the pulp of the physic nut is thicker than that of the dabai, resulting in a greater Dg value. According to Davies (2012), the comparable Dg values for palm oil fruit, nut, and kernel were 23.98 mm, 20.13 mm and 17.23 mm, respectively. Due to the similarity of characteristics between the dabai and palm oil fruitlet as a drupe fruit, the value of Dg is almost the same. However, for the Dg of the whole fruit and nut fraction, there are only minor differences between the two fruits, with dabai having a higher value than palm oil fruit, which is 6.34 % higher for both.

3.3 Surface area

The overall area of an object is defined as its surface area (Kher *et al*., 2018). The surface area for the whole fruit, nut, and kernel of dabai *'Ngemah'* variety were 2269.80 mm^2, 1454.40 mm^2, and 509.80 mm^2, respectively, as shown in Table 1. The whole fruit has the most surface area, followed by the nut, which has 35.92% more. The surface area of the whole fruit is 77.54% more than that of the kernel. The surface area values of these fractions of dabai fruits differed significantly ($P < 0.05$). The rate of energy transfer across the surface area of the whole dabai fruit may be slower than the rate for the nut and kernel since the whole fruit has the maximum surface area value (Sirisomboon *et al.*, 2007).

3.4 Mass of fruit fractions

The amount of matter or substance in an object is defined as its mass (Hardner *et al*., 2001). The mass of fruit fractions is significantly different ($p < 0.05$) as shown in Table 1, with the whole dabai fruit having the greatest average value of 12.38 g. The average value of mass decreases as it approaches the inner fruit fractions. This is evidenced by the fact that the average mass of the dabai fruit's nut and kernel is 5.12 g and 0.99 g, respectively, which is smaller than the average mass of the whole fruit. Whole fruit has a greater average mass value of 58.65% than the nut fraction, while the nut fraction has a higher average mass value of 80.64% than the kernel fraction. Because the pulp of the fruit that covers the nut accounts for 54 to 60% of the total weight of the fruit, the outcome is as expected (Ariffin *et al.,* 2020). When the pulp of the dabai fruit is removed to obtain the nut, around 54 to 60% of the total weight of the dabai fruit is lost. As a result, a lower mass was recorded. The kernel is located at the heart of the dabai fruit, where it is protected by the endocarp of the hard nut. To obtain the kernel inside, the endocarp must be removed, resulting in a lower mass value than the nut of the dabai fruit.

Chua *et al.* (2015) found that the average total fruit mass of different kinds of dabai, comprising *Besar, Biasa, Jernah, Bujur, Seluang* and *Bulat* was 15.33 g, 10.23 g, 7.41 g, 15.28 g, 7.60 g and 13.31 g, respectively. The *Ngemah* variety's average mass is 12.379 g, which falls within the range of the six genotypes. *Biasa, Jernah* and *Seluang* variants are heavier, while *Besar, Bujur* and *Bulat* varieties are lighter. The total seed or nut mass of Dabai fruit for *Besar, Biasa, Jernah, Bujur, Seluang* and *Bulat* is 5.84 g, 3.83 g, 2.83 g, 6.48 g, 3.50 g and 4.78 g, respectively. The total seed or nut mass of the *Ngemah* variety is 5.12 g, which is similar to the total average seed mass of the *Besar* genotype.

3.5 Volume

The volume of an object is the amount of space it takes up (Siswantoro *et al*., 2013). There was a substantial difference between the three fruit fractions. As shown in Table 1, the average volume of the whole fruit, nut, and kernel of dabai fruits were 11300 mm^3, 2040 mm^{3,} and 1000 mm^3, respectively. In comparison to the nut and whole dabai fruit, the kernel of the dabai fruit had the lowest average volume value among the fruit components. This can be explained by the fact that the whole fruits and nuts dimensions are greater than the nut and kernel fraction of the dabai fruit. The length of whole fruit is higher by 11.90% than the nut fraction and 40.70% than the kernel fraction. In addition, the thickness of whole fruit is higher, 23.65% than the nut fraction and 46.54% than the kernel fraction.

Furthermore, the width of the whole fruit is higher (23.82%) than the nut fraction and 67.49% for the kernel fraction. Therefore, the three fruit fractions showed a significant difference ($P < 0.05$). When comparing the lowest value of mean volume for the dabai kernel with other fruit fractions, a high number of Ngemah dabai kernels can be packed in the prescribed volume (Milošević *et al*., 2014).

3.6 Sphericity

The parameter that displays the shape of a solid item in comparison to a sphere of the same volume is surface area (Wilhelm *et al*., 2013). The sphericity values for the whole fruit, nut, and kernel of dabai fruit were 68.67%, 62.35% and 55.13%, respectively, according to Table 1. The whole fruit is higher (4.3%) than the nut fraction and 13.5% than kernel fraction. The nut fraction is higher (7.2%) than the kernel fraction. Any fruit, seed, nut, or grain with a sphericity of more than 70 to 80%, according to Davies (2012), can be classified as spherical. Therefore, the whole fruit, nut, and kernel fractions are not spherical based on the sphericity values of all the dabai fruit fractions. It can be concluded that all of the dabai fruit fractions will slide rather than roll in structural surfaces and this information can be used to construct fruit hoppers in the field (Werby and Mousa, 2016). These fractions of dabai fruits showed significant difference ($P < 0.05$) in sphericity values. Based on Figure 1, the variation in sphericity percentage can be explained by the shape of each fruit fraction. The end of the nut and kernel is pointier than the rest of the fruit, resulting in a lower percentage of sphericity than the rest of the fruit. Furthermore, the shape of each fruit fraction differs, with the overall fruit seeming more 'oval,' the nut fraction having a three-pointed-angle shape, and the kernel fraction having a drop-shape shape (Mokiran *et al*., 2014; Rashid *et al*., 2021).

3.7 Bulk density

Table 1 shows that the mean value of bulk density of the whole fruit, nut, and kernel of dabai fruit is 717.600 kg/m^3, 738.180 kg/m^{3,} and 640.280 kg/m^3, respectively. These values show significant difference ($P < 0.05$) between the three fruit fractions. The highest value of average mean bulk density is the bulk density of the nut of dabai fruit with 738.180 kg/m^3 (nut>whole fruit>kernel). This indicates that the nut needed more space per unit mass than the whole fruit and kernel for the dabai fruit (Coşkuner and Gökbudak, 2016). As a result, the storage bin for dabai nuts must be larger than the whole fruit and kernel of dabai fruit due to its higher bulk density value. The corresponding values of bulk density for palm fruit fractions have the value of 640 kg/m^3, 710 kg/m^{3,} and 690 kg/m^3 for the whole fruit, nut and kernel of palm fruit, respectively. The nut of palm fruit has the highest bulk density of all fruit fractions, similar to dabai fruit. The bulk density of the whole fruit (10.81%) and nut (3.82%) of the dabai fraction is higher

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than that of the palm fruit. Palm fruit kernels, on the other hand, have a higher bulk density (7.21%) than dabai fruit kernels.

3.8 True density

True density is defined as the fraction of mass over the volume of an object, omitting the pores in the material (Rodríguez-Ramírez *et al*., 2012). Table 1 shows that the true density of dabai nut shows the highest mean value with 2755 kg/m^3, followed by the whole fruit and kernel of dabai fruit with values of 1112 kg/m^3 and 990 kg/m^3, respectively (nut>whole fruit>kernel). The true density of these three different fractions of fruit shows significant difference ($P < 0.05$). In percentage, dabai nut is higher (59.6%) than the whole fruit and 64.0% higher than the Dabai kernel. The true density of the whole fruit and nut is higher than the density of water, 1000 kg m^{-3}. As for the kernel of dabai fruit, it has a lower value than the density of water. As a result, this will make the kernel absorb water easily in a short duration and has the tendency to sink in water (Coşkuner and Gökbudak, 2016). However, the value of true density for the nut is slightly above the water density and closer to the value of true density for the kernel. Thus, separating the nutshells from the kernel is impossible to do with the air-blowing or water-floating method (Sirisomboon *et al*., 2007).

3.9 Porosity

Porosity characterizes the quality and texture of dry foods (Singh *et al.,* 2015). Table 1 shows that the porosity of the fruit fractions is significantly different with ($P < 0.05$) where the nut of dabai fruit shows the highest average value with 71.44%. The second highest is the whole dabai fruit with a porosity of 34.77% followed by the kernel of the dabai fruit with an average porosity value of 33.30%. The dabai nut has a greater percentage of 36.70% than the whole dabai fruit and 38.10% than the dabai kernel. In comparison to the whole dabai fruit and kernel, the volume fraction of pores in the Dabai nut is the highest (Singh *et al*., 2015). Because the porosity of the kernel is smaller than that of the whole fruit and the nut of the fruit, bulk kernel aeration is easier than bulk whole fruit and nut aeration (Coşkuner and Gökbudak, 2016).

3.10 Angle of repose

Table 1 shows that the angle of repose of the whole fruit, nut, and kernel is 24.18°, 16.14° and 16.19°, respectively. The angle repose of the whole fruit shows the highest value among the three with 33.3% higher than the dabai nut and 33.0% higher than the dabai kernel. The angle of repose between the dabai nut and dabai kernel has no significant importance. According to Lau (2001), if the angle of repose is less than 25°, the object's flow qualities are excellent, however, if the angle of repose is greater than 25° degrees, the flow is bad. The average angle of repose for all three fractions of dabai fruit is less than 25°. As a result, all three fractions have outstanding flowability. There were, however, a few factors that could have an impact on the angle of repose. The rough exterior surface and the shape of the fruit fractions are two common characteristics that lead to the high angle of repose value (Coşkuner and Gökbudak, 2016).

3.11 Aspect ratio

The ratio between the longer and shorter dimensions is defined as the aspect ratio (Sahoo *et al*., 2009). Table 1 shows that the aspect ratio of the whole fruit, nut and kernel of dabai fruit is 55.69%, 48.14% and 30.84%, respectively. The aspect ratio of these three different fractions of fruit shows a significant difference ($P<0.05$). Whole fruit is higher (7.6%) than the dabai nut and 25.2% higher than the dabai kernel. This is related to the thickness and width of the fruit fraction, where the aspect ratio is defined as the width-to-thickness ratio. When compared to the dabai nut and kernel, the dabai whole fruit has the most width and thickness. Due to the fact that all three fruit fractions have a low aspect ratio percentage, the shape of the three fruit fractions tends to be oblong (Coşkuner and Gökbudak, 2016). This finding supports Ariffin *et al*. (2020)'s assertion that the dabai fruit is oblong. On a flat surface, low aspect ratio fruits will slide rather than roll, and this trait can be used in the construction of hoppers (Ixtaina *et al*., 2008). On structural surfaces, spherical seeds will roll, while flat seeds will glide more easily (Ixtaina *et al.,* 2008).

3.12 Correlation coefficient

Relationships using the Pearson correlation coefficients among the three different fruit fractions of the *Ngemah* variety, which are the whole fruit, nut, and kernel are shown in Table 2. Length was positively correlated with thickness ($r = 0.910$, $p < 0.05$), width (0.961, $p < 0.05$), mass ($r = 0.900$, $p < 0.05$), Dg ($r = 0.9762$, $p < 0.05$) and Da ($r = 0.982$, $p < 0.05$). Length is proportional to the fruit fraction's thickness, width, mass, Dg, and Da. As the length of the fruit fraction increased, the thickness, width, mass, Dg, and Da increased too. Based on this result, it can be concluded that the size of the fruit fractions is bigger and heavier as the length gets longer.

This trend can also be seen in the thickness parameter in Table 2 as thickness is positively correlated with width ($r = 0.960$, $p < 0.05$), mass ($r = 0.976$, $p < 0.05$), aspect ratio ($r = 0.918$, $p < 0.05$), geometric mean

Table 2. Pearson correlation coefficients for physical properties of fruit fractions of Dabai fruit *'Ngemah'* variety.

Variables	L	T	W	Mass	Volume	True Density	Bulk Density	Porosity	Sphericity	Ra	GMD
T	0.910										
W	0.961	0.960									
Mass	0.900	0.976	0.939								
Volume	0.751	0.893	0.804	0.950							
True Density	0.230	-0.007	0.178	-0.097*	-0.346						
Bulk Density	0.754	0.625	0.758	0.561	0.331	0.581					
Porosity	0.245	0.003	0.181	-0.112*	-0.386	0.913	0.552				
Sphericity	0.724	0.897	0.880	0.843	0.756	0.048*	0.617	0.050			
Ra	0.872	0.918	0.969	0.875	0.735	0.218	0.764	0.218	0.949		
D_g	0.972	0.973	0.996	0.953	0.824	0.150*	0.737	0.159	0.863	0.949	
D_a	0.982	0.967	0.993	0.950	0.820	0.156	0.737	0.166	0.837	0.935	0.999

*not significant

diameter ($r = 0.972$, $p < 0.05$) and arithmetic mean diameter ($r = 0.967$, $p < 0.05$). Width is positively correlated with mass ($r = 0.939$, $p < 0.05$), aspect ratio ($r = 0969$, $p < 0.05$), Dg ($r = 0.996$, $p < 0.05$) and Da ($r = 0.993$, $p < 0.05$). This is logical because as the width of the fruit fraction increases, the diameter increases, which results in the increase of Dg and Da. In addition, the aspect ratio is defined as the relationship between the width and the height or length of the object. The formula of aspect ratio, according to Equation (5) which is proportional to width, proves this positive correlation.

Furthermore, mass in Table 2 is positively correlated with volume ($r = 0.950$, $p < 0.05$), Dg ($r = 0.953$, $p < 0.05$) and Da ($r = 0.950$, $p < 0.05$). This means that the more the weight of whole fruit, nuts, or kernels, the greater the volume. Due to their volume, heavier fruit fractions will tend to take up more space. Furthermore, because the volume has a positive relationship with both Dg and Da, it may be argued that the fruit fraction with high Dg and Da is heavier. The volume, Dg, and Da parameters can also be used to determine the mass of the dabai fruit fractions.

Because the measurement of volume was based on the diameters of the fruit, the volumes in Table 2 correlate with both geometric and arithmetic diameters. As a result, volume is favourably connected with Dg ($r = 0.824$, $p < 0.05$) and Da ($r = 0.820$, $p < 0.05$), demonstrating a positive correlation. As a result, fruit fractions with high Dg and Da have a higher volume.

True density in Table 2 is positively correlated with porosity ($r = 0.913$, $p < 0.05$). This is because the porosity parameter depends on the true density. As the pore space inside the fruit fractions grows, the real density of the fruit fractions increases. Furthermore, the real density parameter influences the magnitude of porosity change (Karababa and Coşkuner, 2013). The porosity parameter can forecast the true density for the fruit fractions of dabai fruit due to the high correlation between true density and the porosity parameter.

Bulk density in Table 2 is positively correlated with aspect ratio ($r = 0.764$, $p < 0.05$), Dg and Da ($r = 0.737$, $p < 0.05$). This result explains that fruit fractions with a high value of aspect ratio, Dg and Da, tend to have high bulk density. Sphericity is in Table 2 positively correlated with aspect ratio ($r = 0.949$, $p < 0.05$), Dg ($r = 0.863$, $p < 0.05$) and Da ($r = 0.837$, $p < 0.05$). The diameter of the fruit fractions was affected by the oblong form of the whole fruit and the triangular with pointed shape of dabai nuts and dabai kernels, and the aspect ratio of the fruit fractions simultaneously explains how these parameters greatly affected the sphericity parameter. The aspect ratio, which is defined as the ratio of width to thickness, is the only factor that determines sphericity.

Aspect ratio in Table 2 is positively correlated with Dg ($r = 0.949$, $p < 0.05$) and Da ($r = 0.935$, $p < 0.05$). Dg is positively correlated with Da ($r = 0.999$, $p < 0.05$). The aspect ratio is heavily dependent on the diameter of the fruit. Thus, any changes in D_g and D_a would also affect the aspect ratio. The coefficient of correlation between D_g and D_a is closer to 1 with $r = 0.999$. This relationship proves that the average diameter of all the fruit fractions can be used to calculate the equivalent diameter of all the fruit parts of *Ngemah* variety dabai fruit (Werby and Mousa, 2016).

3.13 Principal component analysis

Principal component analysis was often used as a tool to easily interpret large datasets by reducing the dimensionality while reducing the loss of information (Jollife and Cadima, 2016). According to Table 3, PC1 and PC2 are the only principal components with more value than 1 eigenvalue. The cumulative proportion of

Table 3. Eigen analysis of the correlation matrix.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
Eigen value	9.7533	2.5151	0.3504	0.2043	0.1059	0.0403	0.0215	0.0063	0.0020	0.0007	0.0002	0.0000	0.0000
Proportion	0.7500	0.1930	0.0270	0.0160	0.0080	0.0030	0.0020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cumulative	0.7500	0.9440	0.9710	0.9860	0.9950	0.9980	0.9990	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 4. Eigen vectors.

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
L	0.305	-0.071	-0.459	0.002	-0.154	0.225	-0.083	-0.182	0.562	-0.149	-0.231	-0.252	-0.349
T	0.313	0.093	0.018	0.136	-0.041	-0.508	-0.524	-0.199	-0.376	-0.313	-0.032	-0.116	-0.216
W	0.319	-0.032	-0.016	0.021	-0.075	0.340	0.048	0.057	-0.236	0.139	0.758	-0.158	-0.309
Mass	0.307	0.159	-0.135	0.064	0.170	-0.208	0.251	0.780	0.081	-0.329	-0.003	0.014	0.000
Volume	0.268	0.324	-0.124	0.064	0.406	-0.233	0.579	-0.486	-0.046	0.105	0.006	-0.006	0.000
True	0.043	-0.603	-0.028	0.181	0.746	0.089	-0.190	0.004	0.019	-0.008	0.004	0.001	0.000
Bulk	0.237	-0.341	0.065	-0.873	-0.023	-0.225	0.096	-0.020	-0.024	0.010	-0.004	-0.001	0.000
Porosity	0.042	-0.605	-0.037	0.390	-0.443	-0.333	0.406	-0.031	-0.060	0.041	0.000	-0.003	0.000
Sphericity	0.286	0.046	0.738	0.132	0.002	-0.147	-0.074	-0.017	0.541	0.139	0.095	-0.067	0.000
Ra	0.308	-0.062	0.382	0.036	-0.063	0.522	0.209	-0.059	-0.363	-0.325	-0.437	-0.044	0.000
GMD	0.319	-0.013	-0.106	0.049	-0.089	0.088	-0.125	-0.074	0.070	0.029	0.035	0.917	0.000
AMD	0.318	-0.017	-0.188	0.043	-0.100	0.086	-0.148	-0.104	0.049	-0.089	0.171	-0.189	0.858
Surface	0.318	0.047	-0.107	0.057	-0.020	-0.006	-0.144	0.241	-0.203	0.778	-0.375	-0.122	0.000

variance can also be a reference to pick the best principal component. The cumulative proportion of PC1 (75%) and PC2 (19.3%) is 94.3%, more than 90% where at least 90% of the variance needed to be explained.

Based on Table 4, the first principal component has large positive associations with L, T, W, mass, Ra, Dg, Da and surface area. This component mainly measures the dimension and mass of the fruit fractions. The second component analysis has large negative associations with true density and porosity parameters. This component indicates the volume of pores and voids inside the fruit fractions. Porosity determined the air spaces inside the fruit fractions. This component can be used to know how each fruit fraction reacts in different atmosphere conditions, whether modified or not.

4. Conclusion

Each fraction of the dabai fruit (whole fruit, nut and kernel) has different physical characteristics such as the dimension that consists of three axial parameters (length, thickness, and width), geometric mean diameter (Dg), arithmetic mean diameter (Da), surface area, mass, volume, sphericity, bulk density, true density, porosity, angle of repose and aspect ratio. In terms of length, thickness, Dg, Da, surface area, mass, volume, sphericity, and aspect ratio, the whole dabai fruit has the highest value. On other hand, for true density, bulk density, and porosity, the nut of the dabai fruit is the highest. Meanwhile, the kernel of the dabai fruit showed the lowest value of all physical attributes. From the Pearson correlation study, it showed that all the physical of the dabai's fruit fractions were dependent on each other. Based on principal component analysis (PCA), the first principal component has a large positive association with L, T, W, mass, Ra, D_g, D_a and surface area. It mainly measures the dimension and mass of the fruit fractions. The second component analysis has a large negative association with true density and porosity parameters which indicates the volume of pores and voids inside the fruit fractions. The results of the study will not only be useful in the design of future processing equipment but also in determining the appropriate physical and mathematical model for the optimization of the processing operations.

Conflicts of interest

The authors declare no conflict of interest.

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