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Physical Properties of Full-ripe Dabai (*Canarium odontophyllum miq.* Variety Song) at Different Fractions

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ABSTRACT

Dabai fruit is an exotic and seasonal fruit in Sarawak. Among the varieties available, the Song variety was chosen due to better taste and high demand amongst local consumers. This study determined the physical properties of dabai (Song variety) at three different fractions: whole fruit, nut, and kernel. According to the results, whole fruit had the highest values in geometric mean diameter (27.86 mm), volume (12.70 cm^3), mass (13.89 g), surface area (2442.60 mm^2) and angle of repose (39.06°) when compared to nut and kernel. Bulk density of dabai nut reached the highest with the value of 0.63 gcm^{-3}. Kernel had the highest percentage of porosity (80.50) compared to others. The correlations of physical properties between whole fruit, nut and kernel were further analysed using Principal Component Analysis (PCA). The findings can potentially be useful in the design of handling and processing equipment.

Keywords: Canarium odontophyllum, correlations, fractions, physical properties

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INTRODUCTION

Canarium odontophyllum, known as dabai fruit, is an indigenous and seasonal crop unique to Sarawak. Dabai fruit is composed of a thin layer of skin (epidermis) surrounding the flesh (mesocarp or pulp) and a sub-triangular hard-shell seed with three chambers (endocarp or nut) containing a single kernel. Ariffin et al. (2020) reported

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that the light green skin turns dark purple, and the fleshy pulp becomes creamer yellow, indicating a fully ripe fruit. The 'Song' variety was chosen due to its better taste, high buyer demand, and local consumers' preferences. In recent years, dabai has been promoted by the Agriculture Department of Sarawak as a speciality fruit and a future economic crop of Sarawak (Ding & Tee, 2011; Chua et al., 2015). The dabai fruits are graded into three grades: grade A, grade B, and grade C. Grade A has the biggest size, thicker flesh and larger nuts compared to grades B and C (Hady, 2021).

Size, shape and weight and relationships of physical properties are determined as important to design and optimise a machine for sorting, grading, sizing, handling, packaging, storage and transport of fruits (Altuntaş & Yildiz, 2007; Milošević et al., 2014; Azman et al., 2020). However, detailed studies concerning the correlation of its physical and chemical attributes associated with different fractions are still scarce up to now. Thus, this research aims to (1) determine the physical properties of dabai fruit at different fractions and (2) investigate the correlations between physical properties and dabai fractions. The result of this study will contribute to the evaluation of dabai biodiversity and aid in designing the handling and processing equipment for potential commercial production.

MATERIALS AND METHODS

Fruit Materials

Matured grade A dabai fruit ('Song' variety) was purchased at a local market at Kuching, Sarawak, located in northwest Borneo Island. The fruits were transported on the same day by flight, immediately delivered to the laboratory at Universiti Putra Malaysia, and stored in a freezer (SJC318, Sharp, Malaysia) with a temperature of -14°C upon arrival. A total of 20 random samples of grade A dabai fruit with good quality and free from defect or physical injury were selected for the testing.

Sample Preparation

Twenty replicates of dabai fruits from the bulk sample were chosen. The whole fruit was measured after being thawed for five minutes after being taken out from the freezer. Then, the fruit fractions were manually separated into nut and kernel, as indicated in Figure 1. Firstly, the flesh of the fruit was peeled using a knife to obtain the sub-triangular nut. Notably, the remaining flesh must be

(a)

(b) (c)

Figure 1. (a) Whole fruit, (b) nut, and (c) kernel of Canarium *odontophyllum Miq.*

removed fully, and the nut must be washed under water to ensure an accurate reading. Next, the hard shell of the same set of nut samples was cracked carefully using a c-clamp to obtain its single kernel.

Determination of Geometric Properties

The geometric properties of each fruit fraction examined included dimensions (sizes), sphericity, aspect ratio, volume, and surface area. The size of all fruit fractions was expressed in terms of three spatial dimensions such as length (L), width (W) and thickness (T), that correspond to major, intermediate, and minor diameters, respectively, and was measured using a digital vernier calliper (Series 500, Mitutoyo, Japan) with 0.01 mm sensitivity.

Each fraction's actual volume (V) was measured using the water displacement method (Khoshnam et al., 2007; Ehiem et al., 2016; Yang et al., 2018). The fruits generally have irregular shapes and need to be expressed in standard shapes. Therefore, the whole fruit, nut, and kernel of dabai were presumed to be a standard elliptical shape. Accordingly, ellipsoid (*Vellip*) volume was calculated using Equation 1 (Azman et al., 2020):

$$Vellip = \frac{4\pi}{3}\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)\left(\frac{T}{2}\right) \quad [1]$$

The sphericity (Φ), aspect ratio (AR), geometric mean diameter (D_g), and arithmetic mean diameter (D_a) were calculated by using the following Equations 2 to 5 suggested by Khoshnam et al. (2007), Milošević et al. (2014), Ehiem et al. (2016) and Azman et al. (2020), respectively:

$$\Phi = \frac{(LTW)^{\frac{1}{3}}}{L} \quad [2]$$

$$AR = \frac{L}{W} \quad [3]$$

$$D_g = (LWT)^{\frac{1}{3}} \quad [4]$$

$$D_a = \frac{(L+W+T)}{3} \quad [5]$$

Surface area (SA) can be defined as the total three-dimensional (3D) shape areas of all surfaces. It was calculated using Equation 6 (Burubai & Amber, 2014):

$$A_s = \pi D^2{}_g \quad [6]$$

Determination of Gravimetric Properties

Gravimetric properties like mass, true density, bulk density, and porosity of each fraction were measured. Individual 20 fruit mass (M) was weighed using an electronic balance

(ATY224, Shimadzu Corp., Japan) with a precision of ± 0.0001 mg. The water displacement method was carried out to determine the true density of the fruit fraction. The true density (ρ_t) of the fruit is the ratio of the mass of a fruit sample to the solid volume occupied by the sample, which was calculated using Equation 7 (Altuntaş & Yildiz, 2007).

$$\rho_t = \frac{M_i}{V_i} \quad [7]$$

where M_i – mass of individual fruit (g), V_i – volume of individual fruit (cm^3)

Bulk density (ρ_b) is defined as the ratio of the mass of a fruit sample to its total volume and was determined with a weight per hectolitre tester calibrated in kg per hectolitre (Aydin, 2003). It is the sample mass ratio to the container volume it occupies, as Ehiem et al. (2016) suggested. The bulk density of whole fruit was determined by filling the sample to the brim with a 200 cm^3 measuring cylinder and levelling off the excess samples with a flat object. The whole sample was weighed, and similar steps were repeated by using a 100 cm^3 measuring cylinder to determine the bulk density of the nut and kernel based on the following Equation 8:

$$\rho_b = \frac{M_b}{V_c} \quad [8]$$

where M_b – mass of bulk sample (g), V_c – volume of the container (cm^3)

The porosity (P) of fruit fraction was computed from the values of true density and bulk density using the relationship given by Binoj et al. (2016) using Equation 9:

$$P = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad [9]$$

Frictional Properties

Frictional properties like the angle of repose (θ) were determined at whole fruit, nut, and kernel fractions using Equation 10. The angle of repose is the horizontal angle at which the material will stand when piled. It was determined as suggested by Sessiz et al. (2007), Altuntaş & Yildiz (2007) and Liu (2011) with slight modification. A topless and bottomless cylinder of 168 mm diameter and 163 mm height, 76 mm diameter and 96 mm height, 20 mm diameter and 73 mm height were used for dabai fruit, nut, and kernel, respectively. The samples were placed into hollow cylinders of respective diameters and heights atop a selected base, which is the centre of white paper on a flat surface. The cylinder was lifted slowly until a cone of fruit fractions formed on the paper base.

$$\theta = \frac{h}{r} \quad [10]$$

where θ– angle of repose, h– height of cone of fruit fractions formed, r – radius of cone of fruit fractions formed.

Statistical Analysis

All values are expressed as group mean ± standard deviation and analysed using Minitab Statistic 19 Edition. A one-way analysis of variance (ANOVA) was applied to determine the difference among the means of fractions in the physical fruit properties to determine the differences in the means. Probability values at a 5% level ($p < 0.05$) using Tukey's Honest Significant Difference (HSD) test were significantly different. Correlation coefficients were determined by the Pearson correlation matrix method. Principal Component Analysis (PCA) was performed to evaluate interrelationships among variables and any possible fruit fraction grouping based on similar properties by using the Minitab® 19 procedure.

RESULTS AND DISCUSSION

Determination of Geometric Properties of Dabai Fractions

The geometric properties of different dabai fractions of whole fruit, nut, and kernel are presented in Table 1.

Table 1
Some physical properties of different fractions of dabai fruit

Properties			Whole Fruit	Nut	Kernel
Geometric Property					
Length, L	mm	Mean	37.58 ± 1.95[a]	28.04 ± 1.65[b]	23.65 ± 1.10[c]
		Range	(34.00–42.50)	(25.40–30.80)	(21.90–25.80)
Width, W	mm	Mean	24.33 ± 1.00[a]	15.33 ± 0.96[b]	11.84 ± 0.62[c]
		Range	(22.30–25.70)	(13.40–16.90)	(10.50–12.90)
Thickness, T	mm	Mean	23.69 ± 1.12[a]	14.83 ± 0.92[b]	7.20 ± 0.63[c]
		Range	(21.30–25.40)	(13.20–16.50)	(5.60–8.00)
Sphericity, S		Mean	0.74 ± 0.03[a]	0.66 ± 0.02[b]	0.53 ± 0.02[c]
		Range	(0.70–0.78)	(0.62–0.70)	(0.50–0.57)
Aspect ratio, AR		Mean	1.55 ± 0.08[a]	1.83 ± 0.12[b]	2.00 ± 0.02[c]
		Range	(1.43–1.69)	(1.64–2.10)	(0.50–0.60)
Geometric mean diameter, $_Dg$	mm	Mean	27.86 ± 1.10[a]	18.53 ± 1.01[b]	12.61 ± 0.61[c]
		Range	(25.71–29.51)	(16.50–20.48)	(11.19–13.48)
Arithmetic mean diameter, Da	mm	Mean	28.53 ± 1.13[a]	19.40 ± 1.04[b]	14.23 ± 0.59[c]
		Range	(26.37–30.57)	(17.33–21.40)	(13.00–15.27)
Surface area, SA	mm^2	Mean	2442.60 ± 190.90[a]	1082.00 ± 118.20[b]	501.10 ± 47.40[c]
		Range	(2076.80–2736.50)	(855.40–1317.50)	(393.20–570.40)
Actual volume, V	cm^3	Mean	12.70 ± 1.34[a]	4.75 ± 0.79[b]	0.97 ± 0.32[c]
		Range	(10.00–15.00)	(4.00–6.00)	(0.20–2.00)
Ellipsoid volume, $V_{elli}p$	cm^3	Mean	11.38 ± 1.33[a]	3.36 ± 0.55[b]	1.06 ± 0.15[c]
		Range	(8.90–13.46)	(2.35–4.50)	(0.73–1.28)

Table 1 *(continue)*

Properties			Whole Fruit	Nut	Kernel
Gravimetric Property					
Mass, M	g	Mean	13.89 ± 1.55[a]	5.10 ± 0.49[b]	0.89 ± 0.16[c]
		Range	(10.94–16.93)	(4.38–6.02)	(0.403–1.09)
True density,	g/cm^3	Mean	1.09 ± 0.04[a]	1.09 ± 0.12[a]	0.99 ± 0.29[a]
		Range	(1.02–1.16)	(0.91–1.35)	(0.51–2.02)
Bulk density,	g/cm^3	Mean	0.49 ± 0.02[a]	0.63 ± 0.01[b]	0.18 ± 0[c]
		Range	(0.46–0.52)	(0.62–0.67)	(0.18)
Porosity, P	%	Mean	54.97 ± 2.08[a]	41.05 ± 6.53[b]	80.50 ± 5.20[c]
		Range	(50.03–58.33)	(29.37–54.38)	(64.29–91.03)
Frictional Property					
Angle of repose	°	Mean	39.06 ± 6.82[a]	31.22 ± 2.89[a]	32.09 ± 6.76[a]
		Range	(28.89–47.45)	(28.39–35.59)	(20.69–37.49)

Data are expressed in mean (± standard error) with 20 replicates. Different lower-case letters indicate significant differences ($p \leq 0.05$) by Tukey's HSD test within the same row.

Dimensions

There were significant differences ($p \leq 0.05$) among the dabai fractions with respect to the dimensions. The mean values of length (L), width (W), and thickness(T) for the whole fruit were 37.58 ± 1.95 mm, 24.33 ± 1.00 mm, and 23.69 ± 1.12 mm, respectively. Table 1 indicated that the length had the highest value with 35 % and 37 % differences compared to the width and thickness of the whole fruit, respectively. In a previous study by Chua et al. (2015), the dabai variety 'Song' had the closest length measurement with dabai *Besar* (36.00 mm) and a similar width with dabai *Bujur* (24.00mm).

Meanwhile, dabai nut had the mean values of 28.04 ± 1.65 mm, 15.33 ± 0.96 mm, and 14.83 ± 0.92 mm for length, width, and thickness, respectively. A similar trend was observed in the whole fruit, with the length obviously having the greatest value compared to the width and thickness of dabai nut, with the differences in percentage at 45% and 47%, respectively. In comparison to previous studies, the length and width of the dabai variety 'Song' were higher than those of pistachio nuts (Kashaninejad et al., 2006) but relatively lower than those of pili nut (Gallegos et al., 2013) under different moisture conditions.

Next, the kernel's mean length, thickness, and width values were 23.65 ± 1.10 mm, 11.84 ± 0.62 mm, and 7.20 ± 0.63 mm, respectively. The kernel length had the highest reading compared to thickness and width. Compared to the width and thickness of the dabai kernel, the length is 50% and 70% higher. The length and width of the kernel were compared with other seeds, and it was observed that the length and width of the dabai variety Song's kernel were lower than the pili kernel (Gallegos et al., 2013). In contrast, they were larger than the Ohadi pistachio nut (Kashaninejad et al., 2006).

The whole fruit of dabai consists of the highest value of dimensions with significant difference ($p \leq 0.05$) among all the three fractions (whole fruit > nut > kernel). Therefore, these conclude that the length of whole fruit was 35% and 37% greater than that of nut and kernel. Besides, the width and thickness of whole fruit were 37% and 51% higher than the width of nut and kernel, respectively, while 37% and 70% greater than the thickness of nut and kernel.

Sphericity

Concerning the sphericity of dabai, there were significant differences ($p \leq 0.05$) among dabai fruit, nut, and kernel, as presented in Table 1. The mean sphericity value for the whole fruit was 0.74 ± 0.03. The dabai nut had a mean value of 0.66 ± 0.02 for sphericity. Meanwhile, the dabai kernel's mean value of sphericity was 0.53 ± 0.02. Earlier, Gallegos et al. (2013) reported that the sphericity value for pili nut and its kernel ranged between 0.584−0.5315 and 0.5355−0.5463, respectively. Meanwhile, Jatropha fruit, nut, and kernel gave sphericity values of 0.95, 0.64, and 0.68, respectively (Sirisomboon et al., 2007), which were lower than dabai nut but higher than the kernel for its sphericity. Overall, the whole dabai variety 'Song' fruit ranged between 0.70 to 0.78, tended to roll better, and its shape was an ideal sphere compared to its nut and kernel.

Aspect Ratio

The aspect ratio relates to the width and length of the fruit, which can be calculated to determine its relationship with fruit shape (Miloševićt al., 2014). According to Table 1, there were differences ($p \leq 0.05$) among the dabai fractions with respect to the aspect ratio parameter.

The mean value of the aspect ratio of whole fruit was 1.55 ± 0.09. The dabai nut had a mean value of 1.83 ± 0.12 for the aspect ratio. Meanwhile, the mean value of the aspect ratio of the kernel was 2.00 ± 0.02. Hence, the aspect ratio of the dabai kernel was the highest with the following sequence: kernel > nut > whole fruit. Asoiro et al. (2017) also investigated and reported a similar trend where the kernel had the highest aspect ratio for velvet tamarind with kernel> unshelled> shelled sequence.

Geometric Mean Diameter

Table 1 presents that the D_g mean value of dabai whole fruit was 27.86 mm ±1.10. The dabai nut had a mean value of 18.53 mm ±1.01, while the dabai kernel had 12.61 mm ±0.61. By comparing the different fractions, dabai whole fruit had a 33 % difference from the nut, 55% higher than dabai kernel for D_g. Other than that, the D_g of dabai nut and kernel were relatively lower than pili nut (32.46−33.06 mm) and kernel (18.73−20.03 mm), while tomato fruit had the highest D_g (34.75 mm) compared to dabai variety 'Song'. Overall, it can be concluded that for D_g of dabai variety 'Song', the whole fruit had the highest mean value and differed significantly ($p \leq 0.05$) among all the three fractions (whole fruit > nut > kernel) with the values ranging from 25.71 mm to 29.51 mm (whole fruit), 16.50 mm–20.48 mm (nut), and 11.91 mm–13.48 mm (kernel).

Arithmetic Mean Diameter

Arithmetic Mean Diameter (D_a) is the diameter average of all the particles in the sample. According to Table 1, the D_a of dabai whole fruit, nut, and kernel were recorded at the mean values of 28.53 ± 1.13 mm, 19.40 ± 1.04 mm, and 14.23 ± 0.59 mm, respectively. Meanwhile, their range was from 26.37 mm to 30.57 mm for whole fruit, 17.33 mm to 21.40 mm for nut, and 13.00 mm to 15.27 mm for kernel. A similar trend was observed with the D_a, whereby the whole fruit had the greatest value compared to the nut and kernel, with percentage differences of 32% and 50%, respectively. D_a of all three fractions was significantly different at $p \leq 0.05$ (whole fruit > nut > kernel).

Surface Area

Table 1 shows significant differences ($p \leq 0.05$) amongst whole fruit, nut, and kernel. The mean values of surface areas of the dabai variety 'Song' were 2442.60 ± 190.90 mm^2 (whole fruit), 1082.00 ± 118.20 mm^2 (nut), and 501.10 ± 47.40 mm^2 (kernel). Thus, the highest mean surface area value was whole fruit (2442.60 mm^2), 56% and 79% greater than dabai nut and kernel, respectively. In a previous study, walnut surface area from four different genotypes ranged from 908.37 to 1042.21 mm^2 (Ebrahimi et al., 2009), lower than in the dabai variety 'Song'. Meanwhile, by comparing within the Canarium family, the whole fruit of the dabai variety 'Song' was relatively larger than the surface area of Canarium schweinfurthii Engl fruits (920.72 mm^2) at a particular moisture content range (Ehiem et al., 2019). The surface area is key in determining the shape of the fruits and indicates how the kernels will behave on oscillating surfaces during processing (Ghadge & Prasad, 2012).

Actual Volume and Ellipsoid Volume

According to Table 1, other physical properties of dabai are actual and ellipsoid volume. For the whole fruit of dabai, the mean values of actual volume and ellipsoid volume were 12.70 ± 1.34 cm^3 and 11.38 ± 1.33 cm^3, respectively. It was followed by nut at 4.75 ± 0.79 cm^3 and 3.36 ± 0.55 cm^3, respectively. The values are 0.97 ± 0.32 cm^3 and 1.06 ± 0.15 cm^3 for the kernel's average actual and ellipsoid volumes, respectively. Overall, the whole fruit of dabai had the highest range values of actual and ellipsoid volumes compared to other fractions, which ranged from 10.00 to 15.00 cm^3 and 8.90 to 13.46 cm^3, respectively. As with other geometric attributes, both volumes differ significantly amongst each fruit fraction. Fruit volume plays a vital role in yield traits in horticultural crop processing, and its estimation is mainly related to fruit shape.

Determination of Gravimetric Properties of Dabai Fractions

Mass. There were significant differences ($p \leq 0.05$) among the dabai fractions with respect to the fruit mass. The mean value of the whole dabai fruit mass was 13.89 g ± 1.55. Meanwhile, the dabai nut had a mean weight value of 5.10 g ± 0.49. Lastly, the mean value of kernel weight was 0.89 g ± 0.16. Therefore, the weight of the whole fruit section was the greatest compared to the other fractions within the range of 10.94 g to 16.93 g. Comparing to a study by Chua et al. (2015), the mean of total mass and kernel for different genotypes of dabai were within 7.60 g to 15.33 g and 0.48 g to 1.33 g, respectively. In a previous study, Ding and Tee (2011) recorded the seed weights of two superior bud-grafted clones, 'Laja' and 'Lulong,' which were 7.7g and 5.0 g, respectively. Prasad et al. (2011) stated that the pulp and seed contributed to the bulk of the fruit weight, comprising 46% and 44%, respectively, while peel constituted 10%. Abdul-Hamid et al. (2020) reported that the physical features, including flesh weight, seed weight, and length and diameter of dates, differed significantly (at a 5% probability level) from one variety to another.

True and Bulk Density. Table 1 presents the results of the true density and bulk density of dabai fruit. The results obtained for whole fruit were 1.09 g/cm^3 ± 0.04 and 0.49 g/cm^3 ± 0.02 for both density readings. The mean value of true density for dabai nut was 1.09 g/cm^3 ± 0.12, almost equivalent to the former reading, while 0.63 g/cm^3 ± 0.01 is the mean value of its bulk density. The dabai kernel's mean values were 0.99 g/cm^3 ± 0.29 and 0.18 g/cm^3, respectively, for true and bulk densities. Therefore, the whole dabai fruit and nut shared the same mean values of true density (1.09 g/cm^3 ± 0.12), which were the highest amongst all fractions with no significant differences (whole fruit = nut > kernel). Meanwhile, the highest mean value for bulk density belonged to dabai nut and differed significantly at $p \leq 0.05$ when compared to the other two fractions of dabai fruit (nut >whole fruit> kernel). It may be attributed to the flesh, which is bulkier than the nutshell, such that it causes a reduction in the total mass per unit volume occupied by the flesh.

Porosity. With regard to the porosity of dabai, there were significant differences ($p \leq 0.05$) among dabai fruit, nut, and kernel. The mean porosity values for the whole fruit, nut, and kernel were 54.97% ± 2.08, 41.05% ± 6.53, and 80.50% ± 5.20, respectively. In conclusion, the porosity for the kernel had the highest mean value based on Table 1 with the following sequence: kernel >whole fruit> nut. It may be due to strong attraction amongst the particles within the nutshell, which contributes to the difficulty of fracturing the nut, limiting its internal pores. Bulk density, true density, and porosity are relevant tools in designing the types of equipment related to the separation, sorting, and handling systems.

Determination of Frictional Properties of Dabai Fractions

Angle of Repose. Frictional properties were measured based on the lifting effect of the hollow cylinders containing either 20 replicates of whole fruit, nut, or kernel. As presented in Table 1, the average values of repose angle were recorded five times. The angle of repose mean value for whole fruit was 39.06 ± 6.82°. Next, dabai nut and its kernel were recorded to have an average of 31.22 ± 2.89° and 32.09 ± 6.76°, respectively, for the angle of repose. However, no significant difference ($p \leq 0.05$) existed amongst dabai fractions in terms of the angle of repose. This phenomenon is vital in determining the minimum flow slope in a self-emptying bin or a hopper. Hence, it can be concluded that the dabai nut has the lowest flowability compared to the whole fruit and the kernel.

Correlations Between Physical Attributes

The dependence of the variables amongst physical attributes of dabai fractions was observed by analysis of correlation and presented in Table 2. Linear correlation showed that the whole fruit length (WFL) shared a highly positive correlation with geometric mean diameter (r = 0.89).

Meanwhile, the correlation coefficients between whole fruit width (WFW), geometric mean diameter (WFD_g), arithmetic mean diameter (WFD_a), volume (WFV) and mass (WFM) were highly positive with values of 0.89, 0.83, 0.86, 0.86, respectively. Next, whole fruit thickness (WFT) was positively correlated with WFD_g (r = 0.89), WFD_a (r = 0.83), and WFM (r = 0.84). Furthermore, the correlation coefficients between WFD_g, WFD_a, WFV and WFM were highly positive, with the values of 0.99, 0.93 and 0.92, respectively. As indicated, WFD_a positively correlated with WFV (r = 0.92) and WFM (r = 0.91). The WFV was highly positively correlated with WFM (r = 0.96).

Linear correlation implied that the dimension (length, width, and thickness) of the nut (NL, NW, and NT) shared positive and high correlation with similar variables; for instance, geometric mean diameter (ND_g; r = 0.83, r = 0.87, and r = 0.97, respectively), arithmetic mean diameter (ND_a; r = 0.90, r = 0.80, and r = 0.95, respectively). The ND_g was strongly positively correlated with ND_a (r = 0.99). There were highly negative and positive correlations that existed between volume (NV) with ND (r = − 0.80) and mass (r = 0.80).

Besides, the kernel (KL) length was highly positively correlated with an arithmetic mean diameter (KD_a, r = 0.85). Next, there were highly positive correlations among KT, KD_g (r = 0.93), KD_a (r = 0.84), and KM (r = 0.86). The correlation coefficients among KD_g, KD_a and KM were highly positive, with values of 0.97 and 0.94, respectively. Meanwhile, the correlation coefficients between KD_a and KM and KV and KD were high, with values

Table 2
Correlation matrix of dabai fruit physical properties

Parameter	WFL	WFW	WFT	WFS	WFD_g	WFD_a	WFV	WFM	WFD	NL	NW	NT	NS	ND_g	ND_a	NV	NM	ND
WFL	1																	
WFW	0.42	1																
WFT	0.41	**0.88**	1															
WFS	**−0.64***	0.39	0.41	1														
WFD_g	**0.75***	**0.89***	**0.89***	0.02	1													
WFD_a	**0.84***	**0.83***	**0.83***	−0.12	**0.99***	1												
WFV	**0.69**	**0.86***	**0.79***	0.03	**0.93***	**0.92***	1											
WFM	**0.65***	**0.86***	**0.84***	0.10	**0.92***	**0.91***	**0.96***	1										
WFD	−0.05	0.11	0.28	0.23	0.13	0.10*	-4×10^{-3}	0.29	1									
NL	0.16	−0.35	−0.15	−0.37	−0.12	−0.06	−0.17	−0.21	−0.15	1								
NW	**0.54***	0.22	0.36	−0.30	0.46*	0.49*	0.33	0.36	0.16	0.47*	1							
NT	0.32	−0.06	0.10	−0.30	0.16	0.20	0.09	0.11	0.08	**0.76***	**0.83***	1						
NS	0.36	**0.52***	0.47*	0.05	**0.53***	0.51	0.47	0.55	0.32	−0.41	**0.59***	0.24	1					
ND_g	0.39	-0.07	0.12	−0.37	0.19	0.24	0.10	0.10	0.03	**0.83***	**0.87***	**0.97***	0.17	1				
ND_a	0.34	-0.14	0.06	−0.38	0.13	0.18	0.04	0.03	−0.01	**0.90***	**0.80***	**0.95***	0.04	**0.99***	1			
NV	0.13	**−0.48***	−0.40	−0.50*	−0.28	−0.20	−0.18	−0.20	−0.09	0.29	−0.15	−0.03	−0.47*	0.04	0.10	1		
NM	0.25	−0.34	−0.30	**−0.51***	−0.13	−0.06	−0.10	−0.14	−0.15	0.25	−0.24	−0.17	**−0.55***	−0.07	0.01	**0.80***	1	
ND	0.08	0.41	0.34	0.23	0.32	0.28	0.18	0.19	0.03	−0.19	0.06	−0.06	0.24	−0.07	−0.10	**−0.80***	−0.29	1
KL	0.31	−0.06	−0.19	−0.41	0.04	0.10	0.13	0.03	−0.31	−0.32	−0.25	−0.32	0.02	−0.33	−0.34	0.25	0.29	−0.11
KW	0.28	0.15	0.29	−0.08	0.29	0.30	0.39	0.36	−0.05	0.06	0.17	0.15	0.13	0.14	0.13	0.22	−0.05	−0.44
KT	0.21	−0.28	−0.34	−0.48*	−0.14	−0.08	0.04	−0.09	−0.44	0.07	−0.13	−0.04	−0.19	−0.04	−0.02	0.36	0.41	−0.19
KS	0.05	−0.10	0.03	−0.08	-2×10^{-3}	0.01	0.13	0.08	−0.14	0.36	0.18	0.32	−0.11	0.32	0.34	0.18	0.06	−0.26
KDg	0.33	−0.13	−0.16	−0.46*	0.04	0.10	0.22	0.09	−0.39	−0.03	−0.10	−0.07	−0.07	−0.08	−0.07	0.38	0.33	−0.31
KDa	0.37	−0.08	−0.14	−0.46*	0.07	0.14	0.23	0.12	−0.37	−0.16	−0.15	−0.16	−0.01	−0.17	−0.18	0.36	0.31	−0.29
KV	−0.09	−0.34	−0.34	−0.20	−0.29	−0.26	−0.11	−0.23	−0.44	−0.11	−0.21	−0.11	−0.08	−0.16	−0.15	0.36	0.15	−0.45*
KM	0.28	−0.17	−0.20	−0.44	−0.02	0.05	0.16	0.05	−0.36	0.02	0.01	0.09	0.04	0.05	0.04	0.27	0.12	−0.33
KD	0.14	0.39	0.38	0.19	0.35	0.32	0.16	0.28	0.41	−0.07	−0.01	−0.01	0.12	-1×10^{-3}	−0.02	−0.34	0.04	0.60*

Data are expressed: WF, whole fruit; N, nut; K, kernel; L, length; W, width; T, thickness; S, sphericity; Dg, geometric mean diameter; Da, arithmetic mean diameter; V, volume; M, mass; D, density. Absolute linear correlation coefficients ≥ 0.50 are marked in bold and starred (*)

* Results are significant at $p \leq 0.05$

Table 2 *(continue)*

Parameter	KL	KW	KT	KS	KDg	KDa	KV	KM	KD
KL	1								
KW	0.01	1							
KT	**0.59***	0.32	1						
KS	−0.34	**0.71***	0.47*	1					
KDg	**0.69***	**0.56***	**0.93***	0.44	1				
KDa	**0.85***	0.47*	**0.84***	0.21	**0.97***	1			
KV	**0.51***	0.35	**0.61***	0.24	**0.67***	**0.66***	1		
KM	**0.58***	**0.61***	**0.86***	**0.50**	**0.94***	**0.89***	**0.62***	1	
KD	−0.18	−0.37	−0.33	−0.29	−0.39	−0.36	**−0.80***	−0.45*	1

Data are expressed as K, kernel; L, length; W, width; T, thickness; S, sphericity; Dg, geometric mean diameter; Da, arithmetic mean diameter; V, volume; M, mass; D, density. Absolute linear correlation coefficients ≥ 0.50 are marked in bold and starred (*)

* Results are significant at $p \leq 0.05$

of 0.89 and -0.80, respectively. Also, it was found that the dabai kernel did not correlate with any variables of the whole fruit or nut.

Generally, when dabai fruit, nut, and kernel were compared, the highest correlation among variables was observed between D_g and D_a. These correlations illustrated that the D_g was the best dimensional parameter for weight estimation (Mohsenin, 1986) and can be used to predict each other (Milošević et al., 2014).

These findings parallel the result of Torres et al. (2012), who found that fresh mass is the most closely related variable to diameter.

CONCLUSION

The physical attributes of dabai, variety Song, and grade A were characterised in this study. All properties varied significantly among fruit fractions except for bulk density and angle of repose. The highest significantly positive correlation was found between geometric mean diameter and arithmetic mean diameter amongst all fractions, while actual density was the least correlated to other variables. Relationships existed amongst several other physical variables within each fraction. In comparison across dabai fractions, whole fruit was observed to have several correlations with certain variables from the nut and kernel. This study enhances the knowledge about the variation of physical properties in each fruit fraction, particularly for the dabai variety 'Song,' and may be relevant to crop producers, food processors, or engineers.

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