



Physical Properties of Liberica Coffee (*Coffea liberica*) Berries and Beans

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ABSTRACT

Liberica coffee is the most important coffee species grown in Malaysia. However, there is little or no research at all conducted on coffee berries and green coffee beans since the plant itself is a low income crop in Malaysia. Therefore, research on Malaysian Liberica coffee can help to increase the knowledge of coffee farmers and coffee manufacturers in the processing and handling of the coffee. Physical properties of Liberica coffee berries and beans were investigated the current study. The properties investigated include the size, mass, density, coefficient of friction, angle of repose, fracture force and colour. In comparison to Arabica and Robusta coffee, Liberica coffee has the biggest size, mass, true density and fracture force values but were lower in bulk density in both berries and beans. The Liberica berries and beans were found to be orange-ish and yellowish colour respectively. Angle of repose was low and approximately similar in berries and beans while jute fibre gave the highest friction to both Liberica berries and beans.

Keywords: Coffee bean, Liberica, physical properties

INTRODUCTION

Coffee is one of the most popular beverages consumed around the world. Besides coffee based beverages, coffee beans are also used to produce other products such as coffee

essence, coffee syrup and coffee caramel (Zainun 1991), which are widely utilised in the confectionary industry. The major coffee species planted and traded around the world are Arabica (80%) and Robusta (20%), while the minor species are Liberica and Excelsa which accounts for less than 1% (Wintgens, 2009). In Malaysia, however, the situation is different where the major coffee species planted are Liberica (73%) and Robusta (27%) while Arabica is only planted in highland areas in negligible quantities. This is due to the climatic condition which makes it

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unsuitable to grow Arabica in lowland (MARDI 1986). Azmil (1991) stated that Liberica and Robusta coffee can be suitably cultivated in Malaysia due to its optimum growth temperature of 18 °C to 28 °C (maximum at 34°C). However, Arabica can only be grown at temperatures below 23 °C which is applicable in highland areas only, such as Cameron Highlands in Pahang.

Before a cup of coffee is made, freshly harvested coffee berries have to undergo various processes in the post-harvest operation. Then, the coffee beans will undergo roasting, grinding, packing and transporting processes which require knowledge of basic physical properties data of the coffee beans. Hence, the basic information on physical properties of coffee berries and the green coffee beans are crucial in the design of the coffee processing machinery, and in the development of a mechanised coffee processing system (Ghosh & Gacanja 1970). The coffee berries' size, density, and crushing strength are important in classification of berries, and also in the design of pulper. In designing the handling system, grading and hulling of coffee beans, the information on size, friction, angle of repose, crushing strength and bulk density is crucial (Chandrasekar & Viswanathan 1999). Due to the greater demand for Arabica and Robusta coffee, most commercial coffee processing machinery have standard sizes according to Arabica and Robusta. Hence, it will be difficult to process the Liberica coffee in the Malaysian coffee industry since it possesses different physical attributes.

Many investigations have been done on the physical properties of Arabica and Robusta coffee berries and beans (Chandrasekar & Viswanathan, 1999; Mendonca *et al.*, 2009; Franca *et al.*, 2005; Afonso Jr. *et al.*, 2007). However, data on physical properties of Liberica coffee is scarce, whereby the latest published data was in 1991 (Ghawas & Rubiah, 1991) and some properties which are important in evaluating quality of coffee in the literature are based on non-Malaysian Liberica coffee (Campa *et al.*, 2004; Campa *et al.*, 2005). Therefore, it is the aim of the current study to evaluate the physical properties of Malaysian Liberica coffee species.

MATERIALS AND METHODS

Coffee Sample

Liberica coffee berries and green beans were obtained from a factory producing coffee -Kilang Kopi FAMA Banting (Selangor, Malaysia) - in May, 2010. The coffee berries and beans were then subjected to sorting and selecting processes which were done manually. For berries, only the ripe and fully ripe berries were used whereas the black, immature and defective berries were rejected. Then, the coffee berries were separated into pulp and mucilageous parchments manually. In the current study, the coffee pulp consisted of the epicarp (skin) and mesocarp (pulp). The mucilageous coffee parchment consisted of mucilage, endocarp (parchment), integument (silverskin) and endosperm (bean), as shown in Fig.1. The coffee beans used consisted of mixed beans (which may contain sour or immature beans) but defective beans (black, partly black, broken or infested) were discarded. The beans were processed using a dry method whereby the crushed berries were sun-dried for 7-21 days, depending upon the climate conditions. The aim of the sun-drying process is to reduce the moisture content of the coffee to 12% (Zainun, 1991). The beans were wholly processed by the coffee farmers.

Moisture Content

The coffee pulp was cut into sizes of approximately 0.5 cm (width) x 2.5 cm (length) after being separated from the mucilageous parchment and before it can be tested for its moisture content. The mucilageous parchment and the green coffee beans were used as a whole without any size reduction procedure. Moisture content was determined by drying 3-5g of sample at 105°C in an oven (UNB400, Memmert, Germany) for 24 hours. Triplicate measurements were done (Reh *et al.*, 2006).

Water Activity

The pre-test procedure for coffee pulp, mucilageous parchment and green coffee beans were the same as in Section 2.2, before they can be tested for their water activity. The water activity of sample was determined using a water activity meter (Fast lab, GBX, France). Five measurements were recorded (Vasconcelos *et al.*, 2007).

Size and Dimension

A digital vernier calliper with 0.01 mm accuracy (Series 500, Mitutoyo, Japan) was used to measure the dimensions of the 100 samples of coffee berries and beans, as shown in Fig.2. The length (L), width (W) and thickness (T) measurements were taken. The L, W and T can also be referred as major diameter, intermediate diameter and minor diameter respectively. The mean diameter of geometric (D_g), arithmetic (D_a), square (D_s) and equivalent (D_e) were calculated from Equations (1), (2), (3) and (4), respectively. Sphericity and aspect ratio were calculated by Equations (5) and (6) (Mohsenin, 1986). Surface area was calculated using Equation (7), according to McCabe and others (1986).

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

$$D_a = \frac{1}{3}(W+T+L) \quad (2)$$

$$D_s = \left[\frac{LW+WT+TL}{3} \right]^{\frac{1}{2}} \quad (3)$$

$$D_{equiv} = \frac{D_g + D_a + D_s}{3} \quad (4)$$

$$S_{ph} = \frac{D_g}{L} \quad (5)$$

$$R_a = \frac{W}{L} \quad (6)$$

$$S_d = (\pi D_g)^2 \quad (7)$$

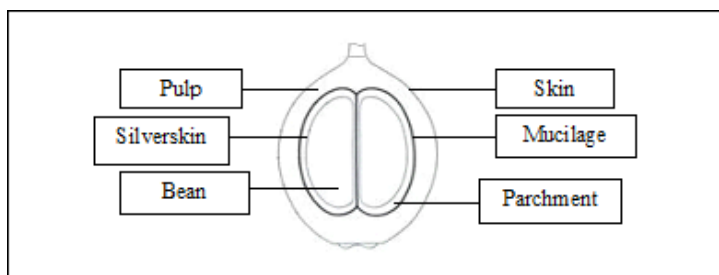


Fig.1: Longitudinal sections of coffee fruit

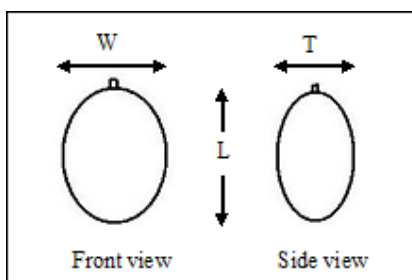


Fig.2: Dimensions of coffee berries

Mass

The mass was determined by a digital balance (ER-120A, AND, Japan), with an accuracy of 0.0001 g. A total of 100 samples were weighed and the values were then divided by 100 to get the average sample weight. After the berries' mass was obtained, each berry was separated into pulp and mucilageous parchments. Then, the pulp and mucilageous parchments were weighed separately to determine their proportions in the berries. Three replications were done (Bart-Plange & Baryeh 2003).

Volume

The volume of berries was estimated by water displacement method (Chandrasekar & Viswanathan, 1999). The test was done 10 times. Following Dutra and others (2001), the bean can be assumed as half a triaxial ellipsoid. The bean volume was calculated using Equation (8).

$$V = \frac{2}{3} \pi abc \quad (8)$$

where 2a, 2b and c are the length, width and thickness of the bean respectively.

Density

The volume of berries obtained in Section 2.6 was used to calculate the berry's true density. In bean true density, 100 beans were first weighed and then each bean volume was calculated by using equation (8). Bean true density was calculated by dividing the weight of 100 beans

with the total volume of the 100 beans (Franca *et al.*, 2005). Bulk density was determined by filling a sample into a 500 ml measuring cylinder. By dividing weight of filled sample with the cylinder volume, bulk density was obtained. The test was done in triplicate (Chandrasekar & Viswanathan, 1999).

Coefficient of Friction

In determining the coefficient of friction, friction surfaces used were aluminium, plywood and jute fibre. The sample was filled into a 10 cm (diameter) x 5 cm (height) PVC cylinder which was placed on the friction surface. The PVC cylinder was then lifted 3 mm from the friction surface so that the cylinder will not touch the friction surface. The friction surface was lifted slowly until the cylinder started to slide down. The angle (θ) between the lifted friction surface and the horizontal surface is known as the static angle of friction between the sample and the friction surface. Coefficient of static friction was obtained from Equation (9) (Bart-Plange & Baryeh, 2003). Five measurements were taken.

$$\mu = \tan \theta \quad (9)$$

Filling Angle of Repose

By following Razavi *et al.* (2007) with a slight modification, filling angle of repose (θ_f) was acquired by filling a round container with a layer of sample. Then, a PVC cylinder (16 cm x 16 cm) was placed at the centre of the container, on top of the sample layer and the cylinder was filled with sample. The cylinder was lifted slowly until the sample formed a cone. The height of the cone was measured and the angle of repose was calculated using Equation (10). The test was replicated five times.

$$\theta_f = \tan^{-1} \left[\frac{2h}{D} \right] \quad (10)$$

where h is the height of the cone and D is the cone diameter.

Emptying Angle of Repose

For emptying angle of repose, a plywood box with a dimension of 20 cm (L) x 15 cm (W) x 30 cm (H) was filled with the sample. The front panel of the box was quickly slid upward to let the sample flow out freely to form a natural heap. Emptying angle of repose (θ_e) was determined by measuring the height of the beans at two points in the sloping bean heap and the horizontal distance between the points as in Equation (11) (Chandrasekar & Viswanathan, 1999).

$$(\theta_e) = \frac{\tan^{-1}(h_2 - h_1)}{x_2 - x_1} \quad (11)$$

where h is the height of sample at two points in the sloping heap and x is the horizontal distance between the two points in the sloping heap. Five measurements were recorded for this test.

Fracture Force

Samples were randomly chosen and positioned horizontally on the platform of Instron testing machine (Instron, 5566, USA). Berries were placed with its front side (Fig.2) facing upward while the beans were placed with their flat sides facing upward. Uniaxial compression was conducted at the rate of 0.83 cm/s. The maximum force recorded during the test before the sample fracture was taken as the fracture force of the sample. From the fracture force, deformation was determined. 10 samples were recorded for its values (Pittia *et al.*, 2007).

Colour

Colour of berries and beans were observed using a colour meter (CR-10, Konica Minolta, Japan). The values of L^* , a^* and b^* obtained were used to determine the chroma and hue angle by using Equations (12) and (13) (Leite da Silveira *et al.*, 2007). The test was replicated five times.

$$\text{Chroma, } c^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (12)$$

$$\text{Hue angle, } h^* = \tan^{-1} (b^*/a^*) \quad (13)$$

RESULTS AND DISCUSSION

Initial Moisture Content and Water Activity

Based on Table 1, the moisture content for pulp was 20.86% and 37.78% for mucilageous parchment. Hence, the mean berries moisture content was 29.32% whereas the beans had 12.53% moisture content. Water activity is 0.943 for pulp and this is 0.946 for mucilageous parchment, with an average of 0.945 for the berries. From the berries' water activity, the berries' rate of deterioration will be fast since the value is near to 1. This also indicates that the berries need to be processed immediately after harvesting to prevent any loss of quality. The bean water activity is 0.603. Both moisture content and water activity values of Liberica beans are in the safe range from further deterioration (Reh *et al.*, 2006; Quiroz *et al.*, 2004).

TABLE 1
Initial moisture content and water activity of Liberica coffee

Coffee	Moisture content (%)	Water activity
Berries	29.32	0.945
- Pulp	20.86	0.943
- Mucilageous parchment	37.78	0.946
Bean	12.53	0.603

Dimension

Dimension or size is important in the screening as well as the grading process, and in evaluating the quality of the food (Sahin & Sumnu, 2006). Dimensions of Liberica coffee berries are displayed in Table 2. Based on the result, the mean length, width and thickness of Liberica berries are 23.44, 20.37 and 18.89 mm, respectively. It was found that the values of the maximum length (29.77 mm) and maximum width (26.11 mm) of Liberica berries were higher compared to 25 mm (length) and 21 mm (thickness) in previous works (Wrigley, 1988). Meanwhile, the mean length (23.44 mm) and width (20.37 mm) of Liberica coffee berries in this study were larger than Arabica (15.65mm, 13.90 mm) and Robusta (13.50 mm, 11.50 mm), as found in Chandrasekar's and Viswanathan's (1999) research. Hence, compared to Arabica and Robusta berries, Liberica berries are bigger and need different processing equipment such as screener and sieve.

The dimension of Liberica beans is presented in Table 3. The mean length, width and thickness of Liberica beans are 11.99 mm, 7.67 mm and 4.67 mm, respectively. The maximum length of Liberica beans is 15.16 mm. However, the mean length (11.99 mm) is lower than in a previous MARDI (1986) study, which was 12.7 mm. This could be attributed to the usage of a mixture of random coffee bean sample in this study, where the immature or green bean may have been included. In addition, the Liberica beans' mean length is longer than Arabica (10.5 mm) and Robusta (8 mm) beans according to MARDI (1986). Therefore, Liberica beans have a bigger dimension than Arabica and Robusta beans and also need equipment (sieves, graders) suited to its bigger size.

TABLE 2
Dimension of Liberica coffee berries

Properties	Minimum	Mean	Maximum	Std. dev.
Length (mm)	19.6	23.44	29.77	1.84
Width (mm)	16.04	20.37	26.11	1.62
Thickness (mm)	15.52	18.89	24.18	1.40
Diameter (mm)				
- Arithmetic	17.05	20.90	26.69	1.37
- Geometric	16.96	20.80	26.59	1.37
- Square mean	17.01	20.85	26.64	1.37
- Equivalent	17.01	20.85	26.64	1.37
Sphericity	0.87	0.89	0.90	0.05
Aspect ratio	0.82	0.87	0.89	0.07
Volume (m ³)	5000 x 10 ⁻⁹	5500 x 10 ⁻⁹	6000 x 10 ⁻⁹	527.05 x 10 ⁻⁹
Surface area (mm ²)	2839.97	4271.09	6978.69	580.76

TABLE 3
Dimensions of Liberica coffee beans

Properties	Minimum	Mean	Maximum	Std. dev.
Length (mm)	9.64	11.99	15.16	1.03
Width (mm)	6.26	7.67	9.25	0.57
Thickness (mm)	3.78	4.67	6.31	0.51
Diameter (mm)				
- Arithmetic	6.56	8.11	10.24	0.49
- Geometric	6.11	7.53	9.60	0.46
- Square mean	6.34	7.82	9.90	0.47
- Equivalent	6.34	7.82	9.91	0.47
Sphericity	0.62	0.63	0.65	0.04
Aspect ratio	0.61	0.64	0.67	0.06
Volume (m ³)	119.45 x 10 ⁻⁹	225.96 x 10 ⁻⁹	463.37 x 10 ⁻⁹	41.95 x 10 ⁻⁹
Surface area (mm ²)	368.56	561.66	909.90	68.75

Sphericity and Aspect Ratio

Sphericity and aspect ratio has been used in heat and mass transfer calculations (Sahin & Sumnu 2006). Sphericity and aspect ratio values of Liberica berries can be observed in Table 2. Liberica berries have 0.89 for mean sphericity and 0.87 for mean aspect ratio. Based on the sphericity value of Liberica berries, it can be observed that the berries have a spherical-like shape since the sphericity exceeds 70% (Eke *et al.*, 2007). Comparing to other species in the work of Afonso Jr. *et al.* (2007). Liberica berries sphericity is only slightly higher than Arabica and Robusta, whereby both berries have a 0.82 sphericity value. From Table 2, with an aspect ratio value of more than 70%, Liberica berries are also more likely to roll than to slide. Hence, Liberica berries have higher sphericity than other coffee species and move by rolling rather than to slide on top of each berry. Sphericity will affect the materials' angle of repose since rounded materials give low angle of repose which means high flowability of materials (Sahin & Sumnu, 2006).

Referring to Table 3, the mean sphericity and the mean aspect ratio of Liberica beans are 0.63 and 0.64, respectively. Liberica beans' sphericity is lower than other major species where the values are 0.68 (Arabica) and 0.72 (Robusta). From Table 3, with an aspect ratio value of less than 70%, Liberica beans are more likely to slide. Low aspect ratio of the Liberica beans also indicates the tendency of the bean shape to be oblong like (Eke *et al.*, 2007). Therefore, Liberica beans have lower sphericity compared to Arabica and Robusta beans and also move on top of each bean by sliding. There is a significant difference in sphericity and aspect ratio between Liberica berries and beans.

Volume and Surface Area

Since coffee berries in Malaysia are processed using the dry method, the berries' volume is important in drying simulation models where the change of volume will lead to a major error in the modelling (Lang & Sokhansaj, 1993). Volume also plays an important role in the roasting process where roasting makes the beans expand (Franca *et al.*, 2005). According to Table 2, the mean volume and mean surface area of Liberica berries are $5500 \times 10^{-9} \text{ m}^3$ and 4271.09 mm^2 , respectively. In the current study, the mean volume of Liberica berries is comparatively higher than Arabica and Robusta. Based on a previous study by Afonso Jr. *et al.* (2003), the maximum volume of Arabica and Robusta berries are $1100 \times 10^{-9} \text{ m}^3$ and $800 \times 10^{-9} \text{ m}^3$, respectively. Liberica berries also have a higher mean surface area of 4271.09 mm^2 compared to the maximum values for Arabica (600 mm^2) and Robusta (450 mm^2) (Afonso Jr. *et al.*, 2003). To conclude, Liberica berries have bigger volume and surface area values than other major coffee species.

The volume and surface area of Liberica beans are presented in Table 3. Based on the result, the mean volume and mean surface area of Liberica beans are $225.96 \times 10^{-9} \text{ m}^3$ and 561.66 mm^2 . The mean volume of Liberica beans is approximately twice the volume of Arabica ($114.9 \times 10^{-9} \text{ m}^3$) and triple the volume of Robusta ($73.7 \times 10^{-9} \text{ m}^3$) beans, based on a study by Mendonca *et al.* (2009). This means that Liberica beans have a bigger volume compared to Arabica and Robusta coffee beans.

Mass

Mass is important in calculation of densities and it can determine quality of materials. From Table 4, the mass composition of Liberica berries are shown. An average Liberica berry's mass is 5.31 g. It is approximately 4 times heavier than the Arabica (1.65 g) and Robusta (1.35g) berry, according to Chandrasekar and Viswanathan (1999). In this study, the pulp to parchment ratio is 60:40 for Liberica and 40:60 for both Arabica and Robusta from the study by Chandrasekar and Viswanathan (1999). This indicates Liberica berries are heavier than Arabica and Robusta berries. Liberica berries also have thicker epicarp (skin) and mesocarp (pulp) with a smaller portion of endocarp (parchment), integument (silverskin) and endosperm (bean) compared to other species of berries. In addition, Ghawas and Rubiah (1991) stated that Liberica berries have a higher quantity of mucilage compared to Arabica and Robusta coffee. This affects the drying rate of Liberica coffee since it is heavier and has more mucilage than other types of coffee.

The mass of an average Liberica bean is 0.26 g (from Table 4). By referring to a study by Ramalakshmi *et al.* (2007), the average bean mass of a Liberica bean evaluated in the current study is higher than Arabica (0.19 g) and Robusta (0.20 g). Hence, Liberica beans are found to be heavier than Arabica and Robusta beans.

TABLE 4
Mass composition of Liberica coffee berries and beans

Properties (g)	Mass	Std.dev.	Percentage (%)
100 berries	530.60	5.50	-
- Pulp	318.34	3.30	60
- Parchment	212.23	2.20	40
One berry	5.31	0.06	-
100 beans	25.72	0.90	-
One bean	0.26	0.01	-

Density

Density is required in a separation process such as hulling and in quality evaluation (Mohsenin, 1978). Bulk density is the material's density when packed or stacked in bulk while true density is the density of the pure substance (Sahin & Sumnu, 2006). The Liberica berries' bulk density is 497.83 kg/m³ while the true density is 1112.13 kg/m³, according to Table 5. Following previous literature, bulk density of Liberica berries is lower than Arabica and Robusta, where the values are 921 kg/m³ and 933 kg/m³. However, Liberica berries' true density is higher than Arabica and Robusta berries (1055 kg/m³) (Chandrasekar & Viswanathan, 1999).

TABLE 5
Physical properties of Liberica green coffee beans and berries

Properties	Berries	Std. dev.	Beans	Std. dev.
Density (kg/m ³)				
- Bulk	497.83	0.66	677.79	1.49
- True	1112.13	84.72	1138.25	-
Coefficient of static friction				
- Plywood	0.41	0.03	0.34	0.01
- Aluminium	0.46	0.03	0.30	0.02
- Jute fibre	0.61	0.02	0.51	0.02
Angle of repose (°)				
- Filling (FAOR)	21.86	3.28	22.49	0.40
- Emptying (EAOR)	21.52	4.44	19.67	0.45
Fracture force (N)	128.52	34.27	308.94	207.34
Deformation (mm)	4.62	0.62	1.16	0.40

From Table 5, Liberica beans' bulk density and true density are 677.79 kg/m³ and 1138.25 kg/m³, respectively. The beans' bulk density is lower than the Arabica and Robusta beans (1200-1300 kg/m³) while the true density is higher following previous studies (600-650 kg/m³) (Rodrigues *et al.*, 2003; Dutra *et al.*, 2001). Data on bulk density of Liberica coffee berries and beans showed that Liberica coffee is packed in lesser amount which could be due to its bigger volume compared to Arabica and Robusta coffee while higher true density of Liberica coffee could be contributed by both its higher mass and volume.

Coefficient of Friction

Coefficient of friction is used in designing storage structures and also agricultural machinery (Mohsenin, 1978). Table 5 shows the coefficient of friction of Liberica berries and beans. From the table, Liberica beans have the highest friction on jute fibre, followed by plywood and aluminium. The surfaces' texture trend is rough (jute fibre), less rough (plywood) and smooth (aluminium). However, the trend is different for the berries where the order is jute fibre (rough), aluminium (smooth) and plywood (less rough). The reason could be the bean's silverskin is less smooth than the berries' skin. Hence, the friction between rough surfaces (plywood and bean's silverskin) is higher compared to friction between rough and smooth surfaces (plywood and berries' skin). Jute fibre offered the maximum friction for both berries and beans which could be due to the micro projections of the jute fibre which offered more resistance to the skin of berries and beans. Besides, rough surfaces have irregularities which make the real area of contact very small and almost independent of the apparent area of the surface (Mohsenin, 1978). Thus, high resistance materials such as jute fibre should be limited to ensure flowability along the tracks of coffee processing.

Angle of Repose (AOR)

Angle of repose can determine the materials' flow behaviour (Ileleji & Zhou, 2008). Therefore, AOR is also used in equipment design and storage structures (Mohsenin, 1978). According to Table 5, Liberica berries and beans filling angle of repose (FAOR) are 21.86° and 22.49° , while the emptying angle of repose are 21.52° and 19.67° , respectively. The FAOR is higher for both berries and beans. AOR will increase with increasing moisture content because the surface layer of moisture which surrounds each particle makes the surface tension effects become predominant in holding solids together (Mohsenin, 1978). The mean value between FAOR and EAOR of berries is 21.69° and this is 21.08° for the beans. The mean value of berries is slightly higher than the beans. This could be due to the sphere-like shape of the berries which make the berries easier to roll, thus, it contributes to an approximately higher value. Meanwhile, the Liberica beans tend to slide on top of each layer of beans making the mean values of FAOR and EAOR lower.

Fracture Force and Deformation

Fracture force is also important in equipment design such as the crusher. The fracture force will determine the maximum force which can be applied to a material. If the maximum force is exceeded, the crusher could damage the coffee beans rather than only the pulp. Table 5 presents the fracture force and deformation of Liberica berries and beans. The values of fracture force for Liberica berries and beans are 128.52 N and 308.94 N, respectively. Based on the result, Liberica berries have lower fracture force compared to the beans. This is because of the nature of the berries which are softer and easier to crush than the beans. According to Chandrasekar and Viswanathan (1999), fracture force values for Arabica and Robusta berries are lower than Liberica berries. The values are 30 N and 50 N, respectively. This shows that Liberica coffee berries need a special crusher for their processing. The value of Liberica berries fracture force

supports the fact from Brando (2009) where the Liberica berries' pulp adheres to the beans strongly, making it difficult to separate the berries' pulp and beans prior to sun drying. For this reason, aggressive pulpers which cut and bruised the pulp have been used in Malaysia rather than the normal pulpers which are used for Arabica and Robusta coffee. In a study by Pittia *et al.* (2007), the Liberica beans have higher fracture force (308.94 N) values compared to Arabica beans (150 N).

Colour

Colour can determine the materials' maturity. Hence, colour can be used in separating ripe berries from green berries. It also assists in the electronic sorting and grading processes (Mohsenin, 1978). This can be applied in sorting the good coffee beans from black or infested beans. Table 6 shows the colour of Liberica berries and beans. The L^* , c^* and h^* values for Liberica berries are 43.76, 49.86 and 39.34, respectively. Liberica beans' values of L^* , c^* and h^* are 39.94, 28.16 and 62.96 each. In comparison to Arabica and Robusta beans, Liberica beans have higher luminosity compared to Arabica (36) and slightly higher than Robusta (39). The chroma value of Liberica beans is higher than Arabica (17) but lower than Robusta (37). Furthermore, both Arabica and Robusta beans have higher values of hue angle which are 88 and 84 respectively which correspond to a yellowish colour (Mendonca *et al.*, 2009).

TABLE 6
Colour values of Liberica coffee berries and bean

Properties	Berries	Std. dev.	Beans	Std. dev.
a^*	37.47	4.77	12.80	0.50
b^*	31.74	10.90	25.08	0.87
L^* - luminosity	43.76	3.17	39.94	1.60
c^* - chroma	49.86	7.01	28.16	0.94
h^* - hue angle	39.34	11.45	62.96	0.69

Comparing Liberica berries and beans, the berries' luminosity (measurement of brightness) and chroma (colour intensity) values are higher than the beans'. Liberica berries' value for hue (element of the colour wheel) angle correspond to an orange shade while the beans correspond to a yellowish colour when referring to the $L^*a^*b^*$ colour system. Wrigley (1988) stated that Liberica berries have a colour ranging from yellow to a dark, reddish brown with spots or flecks of red. Thus, the colour of mature Liberica berries helps in distinguishing the mature from immature berries, while the green of the coffee beans aids in separating bad beans from the good ones.

CONCLUSION

In this study, it was found that Liberica berries have a relatively bigger size, higher sphericity, volume, surface area, mass, true density, and fracture force value, but lower bulk density in comparison to Arabica and Robusta coffee. The order of Liberica berries' coefficient of friction

is jute fibre, aluminium and plywood. While Liberica beans have a bigger size, higher volume, mass, bean average density, fracture force, and luminosity value, but possess lower sphericity, bulk density, and hue angle in comparison to other coffee species. The order of Liberica beans' coefficient of friction is jute fibre, plywood, and aluminium. The physical properties of Liberica coffee berries and beans can be used to determine the quality of the coffee, and assist in machinery design, storage and handling in coffee-related industries.

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