Some Physical Properties of Musk Lime *(Citrus Microcarpa)*

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***Abstract*—**Some physical properties of musk lime *(Citrus microcarpa)* were determined in this study. The average moisture content (wet basis) of the fruit was found to be 85.10 (±0.72) %. The mean of length, width and thickness of the fruit was 26.36 (±0.97), 26.40 (±1.04) and 25.26 (±0.94) mm respectively. The average value for geometric mean diameter, sphericity, aspect ratio, mass, surface area, volume, true density, bulk density and porosity was 26.00 (±0.82) mm, 98.67 (±2.04) %, 100.23 (±3.28) %, 10.007 (±0.878) g, 2125.07 (±133.93) mm2, 8800.00 (±731.82) mm3, 1002.87 (±39.16) kgm-3, 501.70 (±22.58) kgm-3 and 49.89 (±3.15) % respectively. The coefficient of static friction on four types of structural surface was found to be varying from 0.238 (±0.025) for glass to 0.247 (±0.024) for steel surface.

***Keywords*—**Musk lime, *Citrus microcarpa*, physical properties.

I. Introduction

CITRUS microcarpa or popularly known as "limau kasturi" among the locals in Malaysia is a shrub or small tree with a long taproot which can grow up to 2-7.5 m tall. The tree is commonly found in Malaysia, Indonesia, Thailand, Philippines and other Southeast Asian countries. Tree grown from seed begins to bear fruit after about 5-6 years of planting. This can be shortened to 3 years or less by planting asexually propagated seedlings. The flowering and fruiting of the tree is all year round with peaks between August to October each year. *Citrus microcarpa* fruits are round, greenish-yellow with a diameter of about 2-4.5 cm (Fig. 1). About five months after flowering, the fruit will reach full maturity. *Citrus microcarpa* fruits are rich in phosphorus, calcium, iron and vitamin C like other citrus species such as pummelo and mandarin orange. Its juice is traditionally made into drinks to prevent respiratory diseases. The juice is also taken to strengthen the bones and stimulate growth among children. Besides that, the juice is also commonly used as a flavoring ingredient in desserts or as an additive in various food preparations such as fish steak. The pulp of the fruit is used as a major ingredient in beverages, syrups, concentrates, and purees while the peel is made into jams, candies, and marmalade [1].

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In designing machine for handling, processing and storing of these fruits, physical properties such as mass, length, width, thickness, geometric mean diameter, surface area, volume, true density, bulk density, porosity, sphericity, aspect ratio and static friction on different types of surfaces are of paramount importance. In recent years, many researchers have reported physical and mechanical properties of various types of fruits. These include terebinth fruits [2], gumbo fruits [3], *Juniperus drupacea* fruits [4], guna fruits [5], bergamot [6], orange [7], simarouba fruits [8], date [9], apricot [10] and oak fruits [11]. At present, the harvesting and processing of *Citrus microcarpa* fruits in Malaysia are done manually. The operations are labour intensive and time consuming. The aim of this work was to determine some physical properties of *Citrus microcarpa* fruits which could be useful in facilitating the design of machines to handle the process and storage of the fruits.

Fig. 1 Musk lime *(Citrus microcarpa)* fruits

II. Materials and Methods

Fresh musk lime fruits were procured directly from a hypermarket in Raja Uda town in the state of Penang, Malaysia. Immature and broken fruits were removed from the sample. The physical properties of the fruits were determined at the temperature and relative humidity in the range of 21.2 – 25.1 ^{o}C and 70 – 90 % respectively for a period of not more than three days. During this period, the fruits were kept overnight in a refrigerator at 5 ^{o}C to maintain their freshness.

Moisture content of the fruits was determined using AOAC standard method [12]. Five samples of fruit were dried in an air ventilated oven at 80 °C for three days. Moisture content (wet basis) was calculated as:

$$MC(\%) = \frac{M_i - M_f}{M_i} \times 100\% \quad (1)$$

where $MC(\%)$ is the moisture content, M_i is the initial mass and M_f is the final mass of the fruit.

Three principal dimensions namely, length (*L*), width (*W*) and thickness (*T*) of 100 fruits were measured using a digital vernier calliper (Model CD-6BS-Mitutoyo Corporation, Japan) with a resolution of 0.01 mm. The measurements for each dimension were replicated 100 times.

In order to calculate the geometric mean diameter (*D*) for each fruit, the three principal dimensions were used. The geometric mean diameter was calculated based on the following equation [13]:

$$D = (LWT)^{\frac{1}{3}} \quad (2)$$

Sphericity (*S*) is defined as the ratio of the surface area of a sphere having the same volume as the fruit to the surface area of the fruit. The sphericity was determined using the following expression [13]:

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

In order to gather more information about the shape of the fruit, aspect ratio (*R*) of the fruit was determined from the following relationship [14]:

$$R = \frac{W}{L} \times 100\% \quad (4)$$

The mass of 100 individual fruits was measured using an electronic balance (Model PS200/2000/C/2-RADWAG, Poland) with an accuracy of 0.001 g. The measurements were replicated 100 times.

Surface area (*A*) of the fruit was calculated based on the geometric mean diameter using the following formula [15]:

$$A = \pi D^2 \quad (5)$$

Volume (V) for 10 individual fruits was determined using water displacement method as described by Dutta *et al.* [16]. The fruits were weighed and coated with table glue and allowed to dry in order to prevent water absorption. Each fruit was lowered into a measuring cylinder containing water such that the fruit did not float during immersion in water. The weight of water displaced by the fruit was recorded. The ratio of mass to volume of the fruit was treated as true density (ρ_T):

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

where m = mass of individual fruit (kg) and V = volume of individual fruit (m^3).

The bulk density is defined as the ratio of the mass of the sample of the fruits to its total volume. The bulk density was determined according to the method described by Fraser *et al.* [17] by filling an empty 250 ml cylindrical container with *Citrus microcarpa* fruits. The fruits were poured from a constant height, striking off the top level and weighted. Bulk density (ρ_B) was calculated as

$$\rho_B = \frac{m_B}{V_B} \quad (7)$$

where m_B = mass of the sample of fruits (kg) and V_B = volume of container (m^3).

Porosity (*P*) is described as the fraction of the space in the bulk grain that is not occupied by the grain. To calculate the porosity of the bulk fruit, the following relationship [18] was used.

$$P = \frac{\rho_T - p_B}{\rho_T} \times 100\% \quad (8)$$

The coefficient of static friction was determined on four different structural surfaces, namely plywood, galvanized steel sheet, rubber and glass. Each fruit was placed on the surface and raised gradually by screw until the fruit begin to slide. The angle that the inclined surface makes with the horizontal when sliding begins was measured. The coefficient of static friction (μ_s) was calculated using the following expression:

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

where θ = angle that the incline makes with the horizontal when sliding begins.

III. Results and Discussion

The results of some physical properties of *Citrus microcarpa* fruits determined in this study were shown in Table I. The moisture content (wet basis) of the fruits was found to be in the range of 84.14 – 85.95 %. The moisture content is the most vital factor that influences the storability of the fruit. The higher the moisture content, the shorter the storage life of the fruit would be due to the rapid growth of mould on the fruit. Table I shows that the *Citrus microcarpa* fruit has mean moisture content of 85.10%. This would suggest that the fruit has poor storage potential due to its high moisture content. The mean value of length, width and thickness of the fruits was 26.36 (±0.97), 26.40 (±1.40) and

25.26 (±0.94) mm respectively. The dimensions of *Citrus microcarpa* fruits were higher than those for terebinth [2] and gumbo fruits [3] but lower than bergamot [6] and orange [7]. Dimensions of the fruit are of paramount importance in determining the aperture size of the machine to process the fruit. Apart from that, the dimensions could be useful in determining the shape of the fruit. Since two axes (length and width) of the fruits are equal, and the thickness of the fruits are lower than the two axes, the shape of *Citrus microcarpa* fruit is considered to be oblate spheroid. The calculated geometric mean diameter ranges from 24.18 to 28.13 mm with a mean value of 26.00 (±0.82) mm. The geometric mean diameter obtained can be used to determine the volume and sphericity of the fruit theoretically.

The mean of sphericity and aspect ratio of the fruits were 98.67 (±2.04) % and 100.23 (±3.28) % respectively while the mean mass of the fruits was 10.007 (±0.878) g. The sphericity was higher compared to *Juniperus drupacea* fruits [4], bergamot [6] and orange [7]. The high sphericity and aspect ratio of the fruits indicate that the *Citrus microcarpa* fruit is likely to roll on their surfaces rather than slide. This parameter is of utmost importance in designing of hopper to handle the fruits. The average surface area was found to be 2125.07 (±133.93) mm^2 while the mean volume determined for 10 fruits was 8800.00 (±731.82) mm^3. True density and bulk density of the fruits were 1002.87 (±39.16) and 501.70 (±22.58) kgm^{-3} respectively. The reported value of true density for *Juniperus drupacea* fruits [4] and orange [7] are very similar to *Citrus microcarpa* fruits. However, their bulk density was lower compared to *Citrus microcarpa* fruits. The smaller size of *Citrus microcarpa* fruits may have contributed to the higher value of bulk density. This parameter is important in determining the storage capacity of the fruits. The average porosity of the *Citrus microcarpa* fruits was 49.89 (±3.15) %. This value was found to be in the same order as *Juniperus drupacea* fruits [4], orange [7] and date [9] but higher than simarouba fruit [8] and apricot [10]. The porosity of seed is important because it shows the resistance of the fruits to airflow during drying process.

The coefficient of static friction of *Citrus microcarpa* fruits against four types of structural surface was determined. The results were indicated in Table II. The coefficients of static friction for *Citrus microcarpa* fruits were greater than the values reported for *Juniperus drupacea* fruits [4] but lower than orange [7]. The low value of coefficient of static friction may be attributed to the smoother surface of the fruit. It was found that the fruit had the highest coefficient of static friction on plywood and galvanized steel sheet, followed by rubber and the least for glass. This property is of paramount importance in determining the steepness of the storage container, hopper or any other loading and unloading device.

TABLE I
SOME PHYSICAL PROPERTIES OF CITRUS MICROCARPA FRUIT

Physical properties	Unit of measurement	No. of observation	Mean value	Standrd deviation
Moisture content of seed (w.b.)	%	5	85.10	0.72
Length	mm		26.36	0.97
Width	mm	100	26.40	1.04
Thickness	mm	100	25.26	0.94
Geometric mean diameter (GMD)	mm	100	26.00	0.82
Sphericity	%	100	98.67	2.04
Aspect ratio	%	100	100.23	3.28
Mass	g	100	10.007	0.878
Surface area	mm^2	100	2125.07	133.93
Volume	mm^3	100	8800.00	731.82
True density	$kg\ m^{-3}$	10	1002.87	39.16
Bulk density	$kg\ m^{-3}$	10	501.70	22.58
Porosity	%	10	49.89	3.15

TABLE II
COEFFICIENT OF STATIC FRICTION OF CITRUS MICROCARPA FRUITS ON FOUR TYPES OF STRUCTURAL SURFACE

Coefficient of static friction on	No. of observation	Mean value	Standard deviation
Plywood	25	0.247	0.019
Galvanized steel sheet	25	0.247	0.024
Rubber	25	0.240	0.016
Glass	25	0.238	0.025

IV. CONCLUSION

The average moisture content (wet basis) of the *Citrus microcarpa* fruits determined in this study was 85.10 (±0.72) %. The mean of length, width and thickness of the fruits was 26.36 (±0.97), 26.40 (±1.04) and 25.26 (±0.94) mm respectively. The average value for geometric mean diameter, sphericity, aspect ratio, mass, surface area, volume, true density, bulk density and porosity was 26.00 (±0.82) mm, 98.67 (±2.04) %, 100.23 (±3.28) %, 10.007 (±0.878) g, 2125.07 (±133.93) mm^2, 8800.00 (±731.82) mm^3, 1002.87 (±39.16) kgm^{-3}, 501.70 (±22.58) kgm^{-3} and 49.89 (±3.15) % respectively. The coefficient of static friction on four types of structural surface was found to be vary from 0.238 (±0.025) for glass to 0.247 (±0.024) for steel surface. The technical data obtained in this study may be useful in the design of machine for handling and processing of the *Citrus microcarpa* fruits.

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