Studies on geometrical, physical, mechanical and colour properties of mangosteen fruits

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Abstract. Geometrical, physical, mechanical, and colour properties are important parameters in the handling and processing of mangosteens. This study was carried out to form an essential database for mangosteen. The results of the study found that the polar and equatorial diameter of mangosteens were 53.95 ± 8.93 mm and 56.56 ± 9.88 mm, respectively, with the geometric mean diameter of 54.79 ± 9.15 mm. The weight, volume, particle and bulk densities were 97.92 ± 45.33 gr and 95.20 ± 47.57 cm³, 1.06 ± 0.16 gr/cm³ and 0.61 ± 0.02 gr/cm³ respectively. The highest skin strength of polar and equatorial diameter occurred in yellowish-green mangosteens; on the other hand, the lowest of that occurred in brownish-red mangosteens. The highest elasticity of polar and equatorial occurred in dark purple mangosteens; otherwise, the lowest of that occurred in yellowish-green mangosteens. The highest angle of repose and the static friction were 21.58 ± 4.480 and 0.40 ± 0.09, respectively, which occurred on the surface of stainless steel. The total colour difference of yellowish-green and brownish red, yellowish-green, and dark purple and brownish-red and dark purple mangosteens were 63.34 ± 5.68, 66.79 ± 4.54, and 19.95 ± 6.42, respectively.

1. Introduction

Mangosteen (Garcinia mangostana L.) was believed to have originated in the Sunda Islands of the Malay archipelago and the Moluccas of Indonesia [1]. The common name of mangosteen in Indonesia is Manggis. There is a range of vernacular names of mangosteen in Indonesia, such as Manggu (West Java), Manggus (Lampung), Manggusto (North Sulawesi), Manggista (West Sumatera), Mangih (Minangkabau), Mangustang (Halmahera) and Manggis (Java).

The largest production areas of mangosteen in Indonesia is in west Java, including the districts of Tasikmalaya, Bogor, Ciamis, and Purwakarta. In Indonesia, mangosteen is considered as an essential fruit and also exported crops. Indonesia exports fresh mangosteen to Singapore, Japan, China (including Hong Kong and Taiwan), the Netherlands, France and Saudi Arabia [2].

To export of agricultural products is one of the priorities of the current policy of the Indonesian government. To be able to achieve the target of export quality, it is indispensable to apply the proper post-harvesting technologies for the crop. For mangosteen, it has to be well sorted, graded and backed. To procure such operations, information about physical and mechanical properties for mangosteen fruits are essential. The knowledge of the size such as length, width, surface area, volume and weight is necessary to the design of sorting and grading machines; predicting amounts of surface-applied chemicals and describing heat and mass transfer during thermal processes and in the quantification of a bruise, and damage in the handling process. The shape of some fruits is essential in determining their suitability for processing. Many researches were carried out on physical and mechanical properties of...
agricultural product such as Fenugreeks [3], Onions [4,5,6,7,8], Russian olive fruits [9], Coffee fruits [10], Kumquat fruits [11], Jatropha curcas [12], Date fruit [13], Almonds [14], and Sesame seeds [15].

A comprehensive study on mangosteen [2,17] carried out comprising of taxonomy, cultivation, benefit and uses, and postharvest technologies [18]. Recent research on mangosteen is more directed to the use of mangosteen peel as medicine but has not covered the physical and mechanical properties of mangosteen fruits yet. Due to the information lacks about the physical and mechanical properties of mangosteen which are essential to understanding the behaviour of the product harvesting, transporting, sorting, grading, packaging and storage processes. Therefore this work aimed to study the geometrical, physical, mechanical and colour properties to form an essential database for mangosteen.

2. Materials and methods

2.1. Materials preparation

There were three types of mangosteen samples used, i.e., the yellowish-green, brownish-red and dark purple, with the peel moisture content of 71.12 ± 0.50 %, 61.72 ±0.19 %, and 62.36 ± 0.6 % respectively. The sample was taken from Subang and Purwakarta districts, province of West Java. The properties measured comprised of moisture content, geometries, physics, and mechanics. The geometrical properties were measured using digital vernier calliper with an accuracy of 0.01 mm (Series 500, Mitutoyo, Japan). The instrument used to measure the physical properties consisted of electronic balance with accuracy 0.10 g, an analytical balance with an accuracy 0.01 mg, a beaker glass and a graduated cylinder and colourimeter NH 310 (Shenzhen ThreeNH Technology Co., Ltd). The mechanical properties were measured using TA- XT plus Texture Analyser (Stable Micro System Ltd, United Kingdom) and an electrically inclined plane supported by the sensors (Research Center for Appropriate Technology-Indonesian Institute of Sciences). The collected data were statistically analysed to assess the minimum, maximum, means, standard deviation, coefficients of multiple correlations and the linear regressions. The physical and mechanical properties were presented in fitted equations as correlated to the branch dimensions, associated with their $R^2$ values and standard error of estimate (SEE). $R^2$ is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by independent variables in a regression model. In order to get the most substantial correlated variable, the stepwise regression was performed.

2.2. Determination of geometrical properties

2.2.1. Size

The size properties measured included polar diameter ($D_p$), equatorial diameter ($D_e$), arithmetic mean diameter ($D_{am}$), geometric mean diameter ($D_{gm}$), surface area ($A_s$), frontal surface area ($A_{fs}$), and cross-sectional area ($A_{cs}$). The measurement position of polar diameter, equatorial diameter of mangosteen fruits and thickness of its peel were presented in figure 1. The amount of the sample was 30 mixed between the green, maroon red and violet-black mangosteen.

![Figure 1](image_url)
The polar diameter, equatorial diameter and thickness were measured using digital vernier calliper with an accuracy 0.01 mm; arithmetic mean diameter (D_{am}), geometric mean diameter (D_{gm}), surface area (A_s), frontal surface area (A_{fs}), and cross-sectional area (A_{cs}) were calculated by using the following equations [4,5,18,19].

\[
D_{gm} = \left(\frac{D_e + 2D_p}{3}\right)^{1/3}, \text{mm}
\]
\[
D_{am} = \frac{D_e + 2D_p}{3}, \text{mm}
\]
\[
A_s = \pi (D_{gm})^2, \text{mm}^2
\]
\[
A_{fs} = \frac{\pi D_e D_p}{4}, \text{mm}^2
\]
\[
A_{cs} = \frac{\pi (D_e + 2D_p)^2}{9}, \text{mm}^2
\]

2.2.2. Shape

The shape properties included shape index (S_i) and sphericity (\psi), were calculated by using the following equations [[4,5,18,19]]. The mangosteen is considered as spherical if the shape index is less than 1.5. Otherwise, it was regarded as an oval if the shape index is more than 1.5 [5, 19].

\[
S_i = \frac{D_e}{D_p}
\]
\[
\psi = \frac{3}{\sqrt{\frac{D_e D_p^2}{D_e}}}
\]

2.3. Determination of physical properties

The physical properties included mass, volume, particle density, bulk density, porosity, peel content and peel thickness. The measurement was performed on 30 mangosteen samples [20]. The mass of unpeeled sample (M_{up}) and peeled sample (M_p) was measured using an electronic balance with accuracy 0.10 g, and the volume (V) was measured using a graduated cylinder by the water displacement methods. The thickness of peel fruit (T_p) was measured using a digital vernier calliper. The particle density(\rho_p), bulk density (\rho_b), porosity (\varepsilon), and peel content (C_p) were calculated using the following equations [5, 21].

\[
\rho_p = \frac{M}{V}, \text{gr/cm}^3
\]
\[
\rho_b = \frac{M_{101}}{V_{101}}
\]
\[
\varepsilon = \frac{(\rho_p - \rho_b)}{\rho_p} \times 100\%
\]
\[
C_p = \frac{M_{up} - M_p}{M_{up}} \times 100 \%
\]

2.4. Determination of mechanical properties

The mechanical properties measured included skin strength, elasticity, emptying angle of repose and static friction. Skin strength and elasticity were measured using TA- XT plus Texture Analyser Stable Micro System. The emptying angle of repose was measured using an electrically inclined plane
supported by the sensor; the measuring instrument was constructed in Research Center for Appropriate Technology. The static friction ($\mu$) was calculated by using the following equation [21,23,24]. The emptying angle of repose and static friction coefficients were determined to four surfaces materials which commonly used in designing and manufacturing the related equipment for handling and processing the mangosteen fruits, i.e., stainless steel, aluminium, acrylic and plywood.

$$\mu = \tan \theta_e$$

2.5. Colour

In colour measurement, the sample was divided into three colour categories, i.e., the yellowish-green(YG), brownish-red (BR) and dark purple (DP). The amount of sampling of each group was 10, and each sample of each group was measured three times using a colourimeter NH 310. The analysis methods used were CIE (Commission Internationale de L'Eclairage) $L^* a^* b^*$ and CIE $L^* c^* h^*$ coordinates [22]. The value of $L^*$, $a^* b^*$ and $L^* c^* h^*$obtained was used to determine the total colour difference between each group of samples. The total colour difference was calculated using the following equation [22].

$$\Delta E^*_{A-B} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

3. Results and discussions

3.1. Geometrical and physical properties

Table 1 showed the results of measurements of geometrical and physical properties of mangosteen samples included the value of minimum, maximum, mean and standard deviations.

| Minimum | Maximum | Mean  | Std. Deviation |
|---------|---------|-------|----------------|
| $D_p$   | 41.20   | 66.20 | 53.95          | 8.92           |
| $D_e$   | 40.69   | 69.06 | 56.56          | 9.88           |
| $M_{up}$| 37.20   | 158.00| 97.92          | 45.33          |
| $V$     | 30.00   | 170.00| 95.20          | 47.57          |
| $M_p$   | 5.60    | 62.40 | 36.09          | 20.47          |
| $T_p$   | 5.25    | 9.61  | 7.68           | 1.17           |
| $D_{gm}$| 41.40   | 65.91 | 54.79          | 9.15           |
| $D_{am}$| 41.40   | 65.92 | 54.82          | 9.16           |
| $A_s$   | 5381.58 | 13639.66| 9680.58      | 3121.67        |
| $A_{is}$| 1342.83 | 3449.58| 2459.55       | 797.95         |
| $A_{cs}$| 1345.46 | 3410.83| 2422.48       | 781.42         |
| $I_s$   | 0.96    | 1.13  | 1.05           | 0.05           |
| $\psi$  | 41.00   | 66.99 | 53.12          | 8.76           |
| $\rho_p$| 0.82    | 1.46  | 1.06           | 0.16           |
| $\rho_b$| 0.59    | 0.64  | 0.61           | 0.02           |
| $\varepsilon$| 33.09 | 59.72 | 42.27          | 9.08           |
| $C_p$   | 56.18   | 86.41 | 65.27          | 6.72           |

Generally, the result of measurement determined the geometrical mean diameter and the weight of mangosteens were $54.79 \pm 9.15$ mm and $97.92 \pm 45.33$ gr, respectively. The thickness of pericarp and white flesh weight were $7.68 \pm 1.17$ mm and $36.09 \pm 20.47$ gram, respectively. The white flesh content
was 34.74 ± 6.72 %. The porosity, the particle and bulk density were 42.27 ± 9.08 %, 1.06 ± 0.16 and 0.61± 0.02 gram/cm³. The shape index ranged from 1.05 ± 0.05; the value of the shape index less than 1.5 meant that the shape of the mangosteen was regarded as spherical [5, 19].

The geometrical and physical properties are useful in grading, to select the quality of the mangosteen fruits. Mangosteen fruits in CODEX STAN 204-1997 [25] and SNI 3211-2009 [26] are graded according to weight and diameter. In Australia[27] and Thailand [28], mangosteen fruits are graded based on weight. In Australia the fruits are classified to three categories, i.e.,>100 g, 75-100 g and < 75 g, and in Thailand, the fruits are divided into large size, 100-125 g and small size 56-63 g. Besides grading, geometrical and physical properties are also useful to determine the measurement of the container of the packaging.

Results of Pearson Correlation between geometrical and physical properties showed that the weight of unpeeled and peeled mangosteen, volume, the thickness of pericarp, Pericarp contents correlated with polar diameter, equatorial diameter, geometric mean diameter, arithmetic mean diameter, surface area, frontal surface area and sphericity. The stepwise multiple regression determined that the unpeeled weight-related strongly to frontal surface area and geometric mean diameter. The volume correlated with an equatorial diameter; Pericarp thickness and pericarp contents associated with the geometric mean diameter and polar diameter, respectively. The regression equation of that relationship was as follows:

\[
M_{up} = 0.097 A_t + 3.518 D_{gm} + 52.514 \quad R^2 = 0.991 \quad \text{SEE} = 4.1799
\]
\[
V = 4.631 D_e - 166.707 \quad R^2 = 0.924 \quad \text{SEE} = 13.3270
\]
\[
M_p = 0.025 A_t - 25.789 \quad R^2 = 0.962 \quad \text{SEE} = 4.0629
\]
\[
T_p = 0.076 D_{gm} + 3.519 \quad R^2 = 0.855 \quad \text{SEE} = 0.9534
\]
\[
C_p = -0.534 D_p + 94.049 \quad R^2 = 0.502 \quad \text{SEE} = 4.8248
\]

The equation of the relationship of the geometrical and physical properties are determined to know the relationship strength between component properties with one another. That equation could also be used for estimating the value of one parameter from others.

3.2. Mechanical properties
Table 2 showed the minimum, maximum and mean value of skin strength and elasticity of yellowish-green, brownish-red and dark purple of mangosteen samples. Results of the analysis showed that for each group of samples, skin strength of polar diameter was higher than that of equatorial diameter. The skin strength value of polar diameter decreased from the yellowish green to brownish red and then to dark purple, and the similar phenomenon occurred on skin strength of equatorial diameter. Results of paired t-test analysis determined that the difference between skin strength of polar diameter and that of equatorial diameter for brownish red and dark purple was significant (t(9); p <0.05); otherwise there was not any significant difference (t(9); p>0.05) between skin strength of polar diameter and that of equatorial diameter for yellowish-green mangosteen samples. The elasticity value of polar diameter was relatively lower than that of equatorial diameter for each group of the sampling, and the elasticity value increased from the yellowish green to brownish red, then to dark purple. The result of paired t-test analysis determined that there was a significant difference between elasticity of polar diameter than that of equatorial diameter for each group (t(9); p<0.05).
Table 2. Skin strength (g-force) and elasticity (mm) of mangosteens

|              | Minimum   | Maximum   | Mean      | Std. Deviation |
|--------------|-----------|-----------|-----------|----------------|
| YG_SSpolar   | 2099.64   | 3631.15   | 2837.76   | 416.75         |
| YG_Epolar    | 74.76     | 82.43     | 77.58     | 2.30           |
| YG_SSequitorial | 1854.13     | 3672.57   | 2457.86   | 534.78         |
| YG_Eequitorial | 81.46      | 93.73     | 85.24     | 3.22           |
| BR_SSpolar   | 1209.13   | 2852.13   | 1869.25   | 469.45         |
| BR_Epolar    | 71.23     | 84.87     | 78.33     | 3.77           |
| BR_SSequitorial | 567.07   | 1074.76   | 752.90    | 154.45         |
| BR_Eequitorial | 77.59    | 90.38     | 85.33     | 3.96           |
| DP_SSpolar   | 1327.66   | 2316.86   | 1916.32   | 321.53         |
| DP_Epolar    | 77.83     | 81.47     | 79.41     | 1.24           |
| DP_SSequitorial | 573.17     | 1453.12   | 803.86    | 258.59         |
| DP_Eequitorial | 83.66     | 91.03     | 88.07     | 2.71           |

A comparison of the skin strength of polar diameter in yellowish-green samples with that from brownish red and dark purple samples showed that there were significant differences (t(1,9); p<0.05), otherwise there was not any significant difference between brownish red and dark purple samples. A comparison of the skin strength of equatorial diameter with that from brownish-red samples, results of analysis showed that there was a significant difference (t(9); p<0.05); there was a considerable difference between yellowish green and dark purple (t(9); p<0.05); otherwise there was not any significant difference between brownish red and dark purple (t(9); p>0.05).

A comparison of the elasticity of polar diameter in yellowish-green samples with that from brownish-red samples showed that there were no significant differences (t(9); p>0.05); there were substantial differences between yellowish green and dark purple (t(9); p<0.05), otherwise, there was not any significant difference between brownish red and dark purple samples (t(9); p>0.05). A comparison of the elasticity of the equatorial diameter in yellowish-green with that from brownish-red samples showed there were no considerable differences (t(9); p>0.05); there were no significant differences between brownish red and dark purple samples (t(9); p>0.05); but there was a substantial difference between yellowish green and dark purple samples (t(9); p<0.05).

The average polar diameter skin strength of yellowish-green, brownish-red, and dark purple of mangosteen samples were 2.84, 1.87, and 1.96 kg force, respectively. Moreover, the average equatorial diameter skin strength of yellowish-green, brownish-red, and dark purple were 2.46, 0.75, and 0.80 kg-force, respectively. The previously published paper [29] and [30] reported that the polar and equatorial diameter hardness level of the mangosteen decreases from yellowish-green to dark purple. Tongdee, S. C., et al. [29] stated that the polar diameter hardness of yellowish-green, brownish-red and dark purple of mangosteen were 2.09, 1.32 and 1.32 kg-force, respectively; and the equatorial diameter hardness of those were 0.67, 0.49 and 0.39 kg-force.

The difference in mangosteen mechanical properties resulted from this study, and that of the earlier published paper was predicted due to the difference in growing environmental conditions. The mismatch patterns of hardness decline from yellowish-green, to dark purple of mangosteen, between the findings of this study and the earlier published paper was predicted due to the significant difference of the peel mangosteen thickness of the samples. The range rule for standard deviation [30], stated that the maximum value of standard deviation should not more than the difference between maximum and minimum divided by four. Table 1 showed that the standard deviation of peel
mangosteen value (1.17) was higher than that of the difference between maximum and minimum divided by four (1.09).

The mechanical properties like skin strength is an essential parameter in designing the equipment for harvesting. Traditionally, the harvesting methods of mangosteen, ranging from striking the tree with wooden sticks, shaking the branches, using special hooks for detaching the fruits and even climbing the tree. These methods of harvesting are often causing the mechanical injury which bruises the skin of mangosteen fruits. During harvest, fruits should be handled carefully. A 20 cm drop can cause significant damage to the pulp [28]. One of the damage levels could be predicted by skin strength. The skin strength was varied and affected by many factors, such as the geographical area of plantations and soil type. By knowing the mechanical properties such as skin strength, the damage of the fruit during harvest can be avoided; nets will be competent to use to collect the fallen fruits.

Table 3. Angle of repose

|        | Minimum | Maximum | Mean  | Std. Deviation |
|--------|---------|---------|-------|----------------|
| θ_Acry | 9.17    | 29.82   | 16.85 | 4.98           |
| θ_Al   | 9.17    | 27.87   | 17.72 | 4.38           |
| θ_Plyw | 9.88    | 34.03   | 18.97 | 4.88           |
| θ_SS   | 13.19   | 30.24   | 21.58 | 4.48           |

The result of the angle of repose measurement showed that the highest angle of repose was 21.580, occurred on the surface of stainless steel (θ_SS), and on the other hand, the lowest was 16.850, occurred on the surface of acrylic (θ_Acry).

Table 4. Static friction

|        | Minimum | Maximum | Mean  | Std. Deviation |
|--------|---------|---------|-------|----------------|
| μ_Acry | 0.16    | 0.57    | 0.31  | 0.10           |
| μ_Al   | 0.16    | 0.53    | 0.32  | 0.09           |
| μ_Plyw | 0.17    | 0.68    | 0.35  | 0.10           |
| μ_SS   | 0.23    | 0.58    | 0.40  | 0.09           |

Table 3 and 4 showed that the static friction had similar behaviour as the angle of repose, the higher the static friction, the higher the angle of repose. The static friction had a tangential relationship with the angle of repose.

For export purposes, the skin of the fruit should be clean, naturally smooth and no damage marking. Therefore, before grading the mangosteen fruits will be washed, dried and then placed in the grading container. Throwing the fruit from washing bin to grading bin may cause the damage. Instead of throwing, rolling the fruit from cleaning bin to grading bin, applying the sliding plane will be safer. The angle of the sliding plane should be adjusted as small as possible, and the surface plane should be slippery to reduce the collision among the fruits. Tables 3 and 4 showed that the most suitable material used to launch the fruit from the washing bin to the grading bin was stainless steel.

3.3. Colour properties

Results of measurement obtained that the CIE L*a*b* and L*C*h* coordinates of the yellowish-green were (59.81±4.19, -8.10±1.70, 37.74±1.65) and (59.81±4.19, 38.64±1.76, 0.01±0.00). The CIE L*a*b* and L*C*h* coordinates of the brownish-red were (27.23±3.38, 15.11±2.40, 7.18±3.06) and (27.27±3.38, 16.95±2.74, 0.00±0.00) and those for dark purple were (22.73±0.71, 9.18±2.10,
(1.79±0.57) and (22.73±0.71, 9.36±2.14, 0.00±0.00). Results of calculation determined that the total colour differences between the sample. The total colour difference between yellowish-green and brownish-red, yellowish-green and dark purple, and brownish-red and dark purple were 50.56±5.54, 54.60±3.86 and 9.99±4.35, respectively.

Colour properties are essential parameters to identify the ripeness and hardness level, which are useful for determining harvesting time, consumption, grading and transportation. Referred to the earlier published paper [32] and [33] the yellowish-green sample has not been able to be harvested. Inaccurate time harvesting will develop a weak flavour. The brownish-red sample is suitable for harvest to export, and the dark purple sample is suitable for consumption [28]. Besides diameter and weight, colour is also used for grading. The selector device based on weight, diameter, and colour has been developed and applied for tomatoes segregation [34]. According to a previously published paper [2], from the yellowish-green, mangosteen would change the colour to dark purple after six days. Based on that fast change of the colour properties, so packaging and transportation of mangosteen should be managed carefully to avoid the damage caused by the improper packaging and condition of material and vibration during transport. In many parts of Southeast Asia, the fruits are taken to market in baskets, and also in long bundles fruits strung together. In Thailand, the growers wrap each fruit in tissue paper and pack them into a cardboard carton. The box has ventilation holes and contains 24-30 fruits and stored at a temperature of 13-25°C [28].

4. Conclusion

The following conclusions were found from this study about the geometrical, physical, mechanical and colour of three categories mangosteen colour included yellowish-green, brownish-red and dark purple with the moisture content of 71.12 ± 0.50 %, 61.72 ±0.19 %, and 62.36 ± 0.6 % respectively. The shape index of mangosteen ranged from 1.05 ± 0.05; it was regarded as spherical. The weight and volume were 97.92 ± 45.33 gr and 95.20 ± 47.57 cm3, respectively. The peel content and the thickness of pericarp were 65.37 ± 6.72 % and 7.68 ± 1.17 mm, respectively.

A comparison between polar and equatorial diameter, mechanically the skin strength of polar was relatively higher than that of equatorial diameter; otherwise, the elasticity of polar diameter was lower than that of equatorial diameter. The most upper skin strength of polar diameter and equatorial diameter were 2837.76 ± 416.75 and 2457.86 ± 534.78 g-force respectively, occurred in yellowish-green mangosteens; the highest elasticity of polar and equatorial was 79.41 ± 1.24 and 88.07 ± 2.71 mm respectively occurred in dark purple mangosteens. The lowest skin strength of polar and equatorial diameter were 1869.25 ± 469.45 and 752.90 ± 154.45 g-force respectively, occurred in brownish-red mangosteens, and the lowest elasticity of polar and equatorial diameter was 77.58 ± 2.30 and 85.24 ± 3.22 mm respectively, occurred in yellowish-green mangosteens.

The angle of repose of mangosteen had similar behaviour with the static friction; the more elevated the angle of repose, the higher the static friction. Responses from four surfaces, the stainless steel showed the most upper angle of repose and so the static friction. The angle of repose and static friction value of stainless steel were 21.58 ± 4.480 and 0.40 ± 0.09, respectively. From four surface materials, stainless steel was the most suitable materials to use as a sliding plane.

The total colour difference of yellowish-green and brownish red, yellowish-green and dark purple and brownish-red and dark purple mangosteens were 50.36 ± 5.54, 54.60 ± 3.86 and 9.99 ± 4.35, respectively.

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