Characterisation of physical, mechanical and colour properties of *Muntingia calabura* fruits

A Indriati¹*, D D Hidayat¹, R C E Andriansyah¹, A C Iwansyah¹, D N Surahman¹

¹Research Center for Appropriate Technology, Indonesian Institute of Sciences, Jl. KS. Tubun No.5 Subang, West Java, Indonesia

*Corresponding author’s e-mail : ashiindriati@gmail.com

**Abstract.** Physical, mechanical and colour properties are necessary parameters in the handling and processing of *Muntingia calabura* fruits. The study aimed to form physical, mechanical and colour database for *Muntingia calabura* fruits. Results of the study found that the polar and equatorial diameter ranged from 14.30±0.99 mm and 15.51±0.98 mm, respectively. The weight and the volume were 2.49±0.39 g and 1.12±0.21 cm³, respectively. The particle density, bulk density and porosity ranged 0.97±0.10 g/cm³, 0.57±0.03 gr/cm³ and 40.90±6.59% respectively. The average skin strength and elasticity of the average moisture content of 80.79 ± 0.50 % were 309.60±80.89 g-forces and 38.83±1.63 mm, respectively. The angle of repose on the surface of the acrylic, aluminium, stainless steel and plywood was 23.45±5.390, 24.20±4.770, 25.66±5.000 and 25.93±7.850 respectively with the static friction of 0.44±0.12, 0.45±0.10, 0.49±0.11, and 0.50±0.17 respectively. The coordinate CIE L*a*b* c* and h* of the average colour of samples was 44.914±5.011, 30.274±4.055, 10.460±2.787, 32.288±2.722 and 0.008±0.004.

1. **Introduction**

*Muntingia calabura* is known as Jamaican cherry, and in Indonesia, it is known as kersen. *Muntingia calabura* is the sole species in the genus of Muntingia, Family of Elaeocarpaceae; it is originated to southern Mexico, tropical South America, Central America, the Greater Antilles, Trinidad, and St. Vincent [1–3]. This plant is Neotropic that can live well with a tropical climate and can produce flowers and fruit every year continuously. The height of the tree can reach 12 meters with woody stems, erect, round and has a horizontal branching; the leaves hang toward the tip, downy, single ovoid to lanceolate [4]. Kersen fruit is round with a diameter of 1-1.5 cm. Seeds content in fruit ranges from 624-630 grains/kg [5].

The nutritional content of fruits is not inferior to other fruits. In 100 grams of berries contains lir (77.8 g), protein (0.384 g), fat (1.56), carbohydrate (17.9 g), fiber (4.6 g), ash (1.14 g), calcium (1.24 mg), phosphorus (84 mg), iron (1.18 mg), carotene (0.019 g), thiamine (0.065 g), riboflavin (0.037 g), niacin (0.55 g), and vitamin C (80.5 mg) [5]. Traditionally, the flowers and bark are used as an antiseptic and to reduce swelling in a lower degree, and the leaves are used to reduce gastric ulcer and swelling of the prostate gland, and also to lighten a headache and cold [1]. Regarding the previously published paper [3], *Muntingia calabura* has an outstanding medicinal value; there are many types of research carried out on pharmacological of *Muntingia calabura*, e.g. anti-inflammatory, antinociceptive, antiulcer and cytotoxic; it is not only on the fruits but also on other plant shoot components [6,7].
Studies on physical, mechanical and colour properties of *Muntingia calabura* are still rare relatively, on the other hand, there are many studies on the physical and mechanical properties of fruits such as Apple [8,9], orange [10], Physalis peruviana [11], and tomatoes [12,13]. Therefore, this study aimed to provide physical, mechanical and colour properties database for *Muntingia calabura* fruits to design-related equipment purposes. Besides, research using kersen has been carried out using *Muntingia calabura* as an antioxidant [14], anti-inflation [15], extensive antimicrobial activity showing the use of *Muntingia calabura* as a source of new bioactive principles for drug development. On humans and plant pathogens [16], cherry has many benefits in pharmacological activities (for example, cytotoxic, antinociceptive, antiulcer, anti-inflammatory) [3] and others. Cherry's research fruit is still very little, while knowledge related to the characteristics of fruit can be useful for the basis of making appropriate packaging, environmental regulation of fruit maturity, and so forth.

2. Materials and methods

The sample was taken from Cigadung village (Latitude 60°33’27” S’, Longitude 107°045’45” E, and elevation 87 MAMSL), Subang subdistrict, Subang district, West Java province. The instrument used to measure the physical properties included digital vernier calliper, digital balance, analytical balance, baker glass and graduated cylinders. The apparatus used to measure the mechanical was the TA-XT plus Texture Analyser Stable Micro System. The colour was observed using colourimeter NH 310. The collected data were statistically analysed to assess the minimum, maximum, means, standard deviation, coefficients of multiple correlations and the linear regressions. The physical properties were presented in fitted equations as correlated to the branch dimensions, associated with their R2 values and standard error of estimate (SEE); to obtain the best relationship model between the branch dimension the stepwise multiple regression was employed.

2.1. Physical properties

The main physical properties measured included moisture content, polar diameter (Dp), equatorial diameter (De), weight (W) and volume (V). The water content was determined based on the AOAC procedure [17]. Figure 1 showed the position of polar and equatorial diameters. The supporting data of physical properties such as arithmetic mean diameter (Dam), geometric mean diameter (Dgm), surface area (As), frontal surface area (AfS), and cross-sectional area (AcS), shape index (Si), sphericity (ø), particle density(p), bulk density (pb), and porosity (ε) were calculated by the following equations [10,18–21]. The sample population measured were 30, with the mean value of moisture contents ranged from 80.79 ± 0.50 %.

![Figure 1. Position of polar and equatorial diameter of *Muntingia calabura* fruits.](image)

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

\[
\begin{align*}
S_i &= \frac{D_e}{D_p} \\
\phi &= \left( \frac{D_e D_p^2}{3} \right)^{1/3} \\
\rho_p &= \frac{M}{V}, \text{g/cm}^2 \\
\rho_b &= \frac{M_{500}}{V_{500}} \\
\varepsilon &= \frac{V_{500}}{(\rho_p - \rho_b)} \times 100\%
\end{align*}
\]
2.2. Mechanical Properties
The mechanical properties consisted of the skin strength, elasticity, emptying angle of repose and static friction. The skin strength and elasticity measured was performed in three colour categories of *Muntingia calabura* fruits, i.e. pale red, red and dark red, with the moisture content of 80.73 %, 81.32 %, and 80.32 % (wb) respectively. The measurement of each category was carried out in five replications. The angle of repose and static friction was performed to four surfaces, i.e. stainless steel, aluminium, acrylic and plywood. The population sample measured was 30. Figure 2 presented the apparatus for measuring the angle of repose. The principles of apparatus work are that after the power ON, two sensors of ‘b’ will detect the sample on the adjustable plane, then by pressing the start button, the plane will move up, and it will stop after the sample rolling down. The display 'c' would show the value of the angle. The following equation calculated the static friction (μ).

\[ \mu = \tan \theta_e \]

![Figure 2. The Apparatus for measuring the angle of repose (a: Adjustable Plane, b: Sensor 4 units; c: Display; d: ON/OFF Button; e: Start button, f: Water level)](image)

2.3. Colours
The sample of the *Muntingia calabura* was classified into three colour groups, i.e. pale red, red and dark red, which consisted of 30 samples each and observed using high-quality colourimeter NH 310. The analysis methods used were CIE (Commission Internationale de L'Eclairage) L* a* b* and CIE L* c* h* coordinates. Coordinate L* represents the clarity, in which L=0 is black, and L*= 100 is colourless. Coordinate a* represents the shade of red and green, in which a*> 0 indicates red colour and a*< 0 means green colour. Coordinate b* represents the tone of blue and yellow, in which b*> 0 shows the intensity of yellow and b*< 0 indicates the hue of blue. The hue (h*) is the characteristics of the colour, i.e. red, yellow, green, and blue. The clarity is the attribute of the visual sensation according to the appearance of the sample, whether less or more luminous. The chromatism (c*) is the level of colour related to a lower or higher intensity of the colour. Figure 3 showed the geometric coordinates representation of the two colour models.
Figure 3. The CIE L*a*b* and L*C*h* geometrical coordinates systems

The value of L*a* and b* was used to determine the total colour difference between one and the other group [22,23]. The entire colour difference (ΔE*) is the difference between the L*, a*, and b* of one and the other the sample. The value of L*C* and h* would also derive the total colour difference. The following equation [22] calculated the total colour difference.

\[ \Delta E^*_{A-B} = (L_A^* - L_B^*)^2 + (a_A^* - a_B^*)^2 + (b_A^* - b_B^*)^2 \]

Figure 4. The total colour difference in rectangular coordinates (Source: Gordon, 2014 [23])

3. Results and discussions

3.1. Physical Properties

Table 1 showed the statistical description of minimum, maximum, mean and standard deviation of physical properties which was measured.

|                  | Minimum | Maximum | Mean  | Std. Deviation |
|------------------|---------|---------|-------|----------------|
| \( D_p \)        | 12.37   | 16.22   | 14.30 | 0.99           |
| \( D_e \)        | 13.86   | 17.49   | 15.51 | 0.98           |
| \( D_{gm} \)     | 12.98   | 16.47   | 14.69 | 0.94           |
| \( D_{am} \)     | 13.01   | 16.47   | 14.71 | 0.94           |
| \( A_s \)        | 528.99  | 851.71  | 680.52| 86.77          |
| \( A_0 \)        | 138.61  | 216.20  | 174.76| 21.80          |
| \( A_{cs} \)     | 132.87  | 213.03  | 170.45| 21.65          |
Results of the analysis showed that the value of polar diameter was relatively shorter than that of equatorial diameter. The amount of polar diameter ranged from 14.30±0.99 mm, and that of equatorial diameter ranged from 15.51±0.98 mm. The shape index of *Muntingia calabura* fruits ranged from 1.09±0.05. Due to the value of the shape index less than 1.5, the fruit was regarded as spherical [19,21]. The physical characteristic such as shape, size, volume, frontal surface area, density, porosity and colour are essential in designing specific machine or analysis of the behaviour of the product in the handling of materials. In designing the sorting machine which applies pneumatic or electrostatics as an example, the shape of the product should be firstly defined due to any product shape has different behaviour. In designing the drying machine, the frontal surface area and geometrical diameter are required to determine terminal velocity, drag coefficient and Reynold number needed to calculate thermal diffusivity in heat transfer.

**Table 2.** Pearson correlation and significant level among the branch of physical properties

|       | Dp   | Dc   | Dcm  | Dam  | A1   | A2   | Acs  | Is   | ø    |
|-------|------|------|------|------|------|------|------|------|------|
| W     | 0.832** | 0.703** | 0.835** | 0.834** | 0.834** | 0.819** | 0.833** | -0.292 | 0.249 |
| V     | 0.953** | 0.919** | 0.994** | 0.995** | 0.996** | 0.999** | 0.997** | -0.188 | 0.130 |
| ρp    | -0.465** | -0.593** | -0.532** | -0.536** | -0.535** | -0.561** | -0.538** | -0.089 | 0.133 |
| ρb    | 0.129 | -0.001 | 0.092 | 0.091 | 0.092 | 0.071 | 0.091 | -0.199 | 0.198 |
| ε     | 0.498 | 0.994 | 0.630 | 0.634 | 0.628 | 0.709 | 0.634 | 0.291 | 0.294 |

** Significant level at the 0.01 (2-tailed).
* Significant level at the 0.05 (2-tailed).

Table 2 showed that weight, volume, particle density and porosity correlated with polar diameter, equatorial diameter, geometric mean diameter, arithmetic mean diameter, surface area, frontal surface area and cross-section area (p (Sig 2-tailed)<0.05), but did not correlate with shape index and sphericity (p (Sig 2-tailed) >0.05). There was no correlation between bulk density and polar diameter, equatorial diameter, geometric mean diameter, arithmetic mean diameter, surface area, frontal surface area, cross-section area, shape index and sphericity (p (Sig 2-tailed) >0.05). Results of paired t-test analysis determined that the geometric mean diameter influenced weight; frontal surface area, polar and equatorial diameter influenced volume; equatorial diameter influenced particle density, and the frontal surface area affected porosity. The following equations were the best statistical models resulted from stepwise multiple regression analysis. Instead of knowing the relationship strength between
component properties with one another, this regression equation was also could be used as an alternative to predict one properties parameter by another.

\[
\begin{align*}
W &= 0.348 D_{gm} - 2.612 \\
V &= -0.045 A_t + 0.281 D_e - 0.248 D_p + 1.312 \\
\rho_p &= +0.061 D_e + 1.926 \\
\varepsilon &= -0.170 A_t + 70.539
\end{align*}
\]

R\(^2\) : 0.697 SEE: 0.2186

R\(^2\) : 1.00 SEE: 0.0029

R\(^2\) : 0.351 SEE: 0.0836

R\(^2\) : 0.315 SEE: 5.5538

3.2. Mechanical properties

Figure 5 showed a typical graph of skin strength of *Muntingia calabura* in different moisture contents. The chart 1 was the skin strength of pale red sample which had moisture content of 80.73% (wb); graph 2 and 3 were the that of red and dark red samples which had moisture contents of 81.32% and 80.32% respectively.

![Figure 5](image_url)

**Figure 5.** A typical graph of *Muntingia calabura* skin strength in various moisture contents.

![Figure 6](image_url)

**Figure 6.** The Interval plot of skin strength and elasticity of *Muntingia calabura* fruits

Figure 6 showed the highest amount of skin strength was reached at the moisture content of 80.73%, then it decreased at the moisture content of 81.32% and increased anymore at the moisture content of 80.32%. The weakening of skin strength from 403.53 ± 32.19 to 244.53 ± 58.14 g-force was due to the decreasing of moisture content from 81.32% to 80.73%. The state of its cell walls determines the skin strength of fruit. During ripening the cell wall begins to break down, and as a result, the fruit starts to get softer [21]. The decreasing of skin strength is also affected by the fluid pressure inside the plasma membrane called turgor pressure. The decreasing of moisture content results in the decreasing of turgor pressure which reduces the amount of skin strength [24]. The increase in skin strength from 244.53 ± 58.14 to 280.72 ± 33.40 g-force was suspected due to a change

[Image 182x426 to 408x555]
in water content of 80.73%, to 80.32%, resulted in a drying process which affected in the cell wall become drier and increased the amount of skin strength. The elasticity of *Muntingia calabura* fruits showed similar behaviour with skin strength. Figure 6 also showed that moisture content affected skin strength and elasticity. Mechanical damage to fruits often occurs in harvesting time. The damage fruits can seriously affect the fungi attack; as a result, its quality decreases, and economically it will reduce the selling price. To avoid the mechanical damage, so that in harvesting, requires an appropriate device. In designing of equipment or determining the material of harvesting, the data of mechanical properties such as skin strength or hardness are needed. The soft material like net, it may be used to collect fallen fruits.

Table 3. Paired sample test among three groups of samples

| Texture Profile | Pairs                  | t     | df | Sig. (2-tailed) | Std. Error Mean |
|-----------------|------------------------|-------|----|-----------------|-----------------|
| Skin Strength   | Pale red – Red         | 4.014 | 4  | 0.016           | 39.620          |
|                 | Pale red – Dark red    | 5.926 | 4  | 0.004           | 20.7261         |
|                 | Red – Dark Red         | -1.364| 4  | 0.244           | 26.5266         |
| Elasticity      | Pale red – Red         | 0.219 | 4  | 0.838           | 1.5592          |
|                 | Pale red – Dark red    | 0.018 | 4  | 0.987           | 0.5138          |
|                 | Red – Dark Red         | -0.248| 4  | 0.816           | 1.3368          |

Table 3 showed the comparison of skin strength and elasticity among the three groups of the sample, i.e. pale red, red and dark red. Results of analysis determined that there were significant differences of skin strength of pair pale red-red and pale red – dark red (t(1,4); p<0.05), otherwise there was not any significant difference of pair red-dark red (t(1,4); p>0.05); whereas there were not any significant differences of elasticity among all of the pairs (t(1,4); p>0.05). In determining the height of a pile of fruit when stored can utilize the value of skin strength and elasticity, such as research conducted by Iswahyudi, et al. in determining the maximum load that can be received by guava fruit without causing damage during packaging [25].

3.3. The angle of repose and static friction

Table 4 showed that plywood had the highest angle of repose, whereas acrylic has the lowest one. The value of the angle of repose of plywood ranged from 25.93 ± 7.850, whereas that of acrylic was 23.45± 5.390. The static friction had the same behaviour as the angle of repose. There was a positive tangential relationship between the angle of repose and static friction, the higher angle of repose the more significant static friction. The comparison among the four surfaces of the angle of repose and static friction, table 5 showed that there were not any significant differences (t(1,29); p>0.05).

Table 4. Statistical description of an angle of repose and static friction

| The Angle of Repose, θ° | Static Friction, μ |
|-------------------------|-------------------|
|                         | Min    | Max    | Mean   | Std. Deviation | Min    | Max    | Mean   | Std. Deviation |
| Acrylic                 | 14.60  | 36.39  | 23.45  | 5.39          | 0.26   | 0.74   | 0.44   | 0.12          |
| Aluminium               | 11.18  | 35.44  | 24.20  | 4.77          | 0.20   | 0.71   | 0.45   | 0.10          |
| Stainless Steel         | 16.26  | 36.39  | 25.66  | 5.00          | 0.29   | 0.74   | 0.49   | 0.11          |
| Plywood                 | 11.29  | 43.02  | 25.93  | 7.85          | 0.20   | 0.93   | 0.50   | 0.17          |
Table 5. Paired sample test of angle of repose and static friction on various surfaces

| Pairs       | t   | df | Sig. (2-tailed) | Std. Error | Mean | Pairs       | t   | df | Sig. (2-tailed) | Std. Error | Mean |
|-------------|-----|----|-----------------|------------|------|-------------|-----|----|-----------------|------------|------|
| θSS-θAl    | 1.085 | 29  | 0.287          | 1.3423     | 0.287 | μSS-μAl    | 1.116 | 29 | 0.274          | 0.02897    | 0.02897 |
| θSS-θAcry  | 1.497 | 29  | 0.145          | 1.47671    | 0.145 | μSS-μAcry  | 1.458 | 29 | 0.156          | 0.03201    | 0.03201 |
| θSS-θPlywd | -0.144 | 29  | 0.886          | 1.87911    | 0.886 | μSS-μPlywd | -0.298 | 29 | 0.768          | 0.04145    | 0.04145 |
| θAl-θAcry  | 0.624 | 29  | 0.537          | 1.20982    | 0.537 | μAl-μAcry  | 0.547 | 29 | 0.588          | 0.02619    | 0.02619 |
| θAl-θPlywd | -1.296 | 29  | 0.205          | 1.33211    | 0.205 | μAl-μPlywd | -1.516 | 29 | 0.140          | 0.02947    | 0.02947 |
| θAcry-θPlywd | -1.381 | 29  | 0.178          | 1.79703    | 0.178 | μAcry-μPlywd | -1.495 | 29 | 0.146          | 0.03947    | 0.03947 |

Designing of storage and handling systems for spherical fruits requires data on bulk density and friction coefficients on various bin wall materials, emptying and filling angles of repose. Pressures and loads on storage structures require bulk density, angle of repose and friction coefficients against bin wall materials. Also, the design of hoppers for processing machinery requires data on bulk density and angle of repose. The static friction is used to determine the angle at which chutes must be positioned in order to achieve a consistent flow of materials through the chute. This information is useful in sizing motor requirements for transportation and handling [26].

3.4. Colours

Table 6 showed the average colour value of the entire samples. The geometric coordinates CIE L*a*b* and L*c*h* were (44.914 ± 5.011, 30.274 ± 4.055, 10.460 ± 2.787) and (44.914 ± 5.011, 32.288 ± 2.722, 0.008 ± 0.004).

Table 6. The CIE L*a*b* and L*c*h* coordinates of averages colour of samples

| Minimum | Maximum | Mean | Std. Deviation |
|---------|---------|------|----------------|
| E*      | 47.06   | 61.11| 55.497         |
| l*      | 36.97   | 55.17| 44.914         |
| a*      | 16.67   | 35.27| 30.274         |
| b*      | 6.37    | 20.30| 10.460         |
| c*      | 25.80   | 36.38| 32.288         |
| h*      | 0.00    | 0.02 | 0.008          |

Table 7 showed the geometric coordinates of three categories of sample. The CIE L*a*b* coordinates of pale red, red and dark red were (50.905 ± 2.466, 25.994 ± 4.146, 13.680 ± 2.387), (43.956 ± 1.778, 32.989 ± 9.269 ± 1.043) and (39.881 ± 1.880, 31.839 ± 1.700, 8.431 ± 0.779) respectively; the The CIE L*c*h* of them were (50.905 ± 2.466, 29.642 ± 1.137, 0.009 ± 0.004) and (39.881 ± 1.880, 32.942 ± 1.763, 0.008 ± 0.003), respectively. Results of analysis found that the colour of fruits was dependent on moisture content. Referred to a previously published paper that the degree of colours showed a proportional degree of chemical content. The red colour of fruits is due to lycopene, also belonging to carotenoids, such as α and β carotene; the dark red or even purple colour is due to anthocyanins and the yellow on the pale red to flavonoids [27].
Table 7. The CIE L*a*b* and L*c*h* coordinates of three categories samples

|        | Pale red | Red    | Dark red |
|--------|----------|--------|----------|
| Mean   | E*       | 58.996 | 55.760   | 51.737   |
|        | l*       | 50.905 | 43.956   | 39.881   |
|        | a*       | 25.994 | 32.989   | 31.839   |
|        | b*       | 13.680 | 9.269    | 8.431    |
|        | c*       | 29.642 | 34.282   | 32.942   |
|        | h*       | 0.006  | 0.009    | 0.008    |
| Std. Deviation | 1.304 | 1.627   | 2.348    |
|        | 2.466    | 1.778   | 1.880    |
|        | 4.146    | 1.128   | 1.700    |
|        | 2.387    | 1.043   | 0.779    |
|        | 2.558    | 1.137   | 1.763    |
|        | 0.003    | 0.004   | 0.003    |

Figure 7. The three categories colours of samples

| Pairs         | Minimum | Maximum | Mean | Std. Deviation |
|---------------|---------|---------|------|----------------|
| 1 Δ Pale red -Red | 2.36    | 23.28   | 11.180 | 5.178          |
| 2 Δ Pale red – Dark red | 7.15    | 25.67   | 13.980 | 4.488          |
| 3 Δ Red – Dark red   | 1.33    | 9.64    | 5.022  | 2.185          |

Table 8. The total colour difference between the three categories of samples

4. Conclusion
The results showed that the Muntingia calabura fruit shape index was considered round. The results of the paired t-test analysis determine that the geometric mean diameter affects the weight; frontal surface area, polar, and diameter are affected by volume; the diameter of the equator affects the density of the particles, and the surface area of the front affects the porosity. These physical properties are useful for designing equipment, especially for separation and drying. The average skin strength and elasticity of water content averaged 80.79 ± 0.50%. This mechanical property is essential to design and determine material harvesting equipment. The total color difference between the three sample groups, namely ΔE* pale red-red, ΔE* pale red-dark, and ΔE* red-dark-red. Instead of using
it as an indicator to identify harvest time and consumption time, color parameters are also crucial for designing color picker instruments.

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