Statistical Analysis on The Geometric, Physical and Mechanical Properties of Dried Robusta Coffee Cherry Resulting From Natural System Processing

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Abstract. The study conducted to evaluate the in-between correlation parameters of size, shape, physical and mechanical properties to provide information of physical and mechanical properties of the dried Robusta coffee cherry in relation with the development of coffee processing equipment. The physical and mechanical properties of the dried cherry were measured. The relationship in-between the physical and mechanical properties was analyzed using the stepwise regression analysis. The results of the study showed that polar diameter, equatorial diameter, thickness, geometrical diameter, arithmetic diameter, and surface area were dependent on volume with the correlation coefficient of 0.738, 0.761, 0.775, 0.994, 0.999 and 0.999 respectively. The sphericity was dependent on bulk density with a correlation coefficient of 0.437. The shape index, cross-sectional area and frontal surface area were dependent on particle density with the correlation coefficient of 0.959, 1.00 and 0.967 respectively. The correlation coefficient of the relationship between static friction and angle of repose on acrylic, stainless steel, and plywood were 0.772, 0.700, 1.000 and 0.930 respectively; otherwise, there was no correlation between the static friction and the filling angle of repose. The hardness of the dried cherry had a weak correlation with the fracturability.

Keywords: coffee, natural, physical, mechanical, properties

1. Introduction
In Indonesia, coffee was one of the commodities that played an essential role in supporting efforts to increase non-oil exports. Coffee contributed around 10.1 percent of the entire export value of agricultural products, or 0.5 percent of non-oil exports, or 0.4 percent of the total export value [1]. Besides that, coffee was also a source of employment and income sources for farmers or other economic actors involved in both on-farm and off-farm activities.

The coffee development area reached 1.2 million hectares which consisted of 958 thousand hectares of Robusta coffee (77.77%) and 251 thousand hectares of Arabica coffee (22.23%). From that area, the coffee plantation was almost 96.15% cultivated by smallholders, involving around 1.9 million households, 1.99% grown by large private estates, and the rest of 1.82% improved by government estate.

Concerning the process of coffee cherry processing, farmers generally applied dry system processing, because it was relatively more straightforward than that of another process dry coffee bean processing also was known as a natural process. This process included the oldest technique available in the history of coffee processing. In the natural process of coffee, cherries harvested will then be
spread over the surface of the plastic bases and dried in the sun. Some coffee producers sometimes left
out in the brick terrace or tables that had an airflow on the bottom. When dried in the sun, these coffee
beans should be turned back periodically so that the coffee beans drained evenly, and avoided decay.
In the natural process, dried coffee fruit is still in the form of cherry, complete with all of the layers.
The dried coffee cherry produced from this natural process then processed into the green bean and
ready for roasting.

Knowledge of size, shape, physical and mechanical properties of coffee are essential in processing,
designing, and manufacturing of equipment. Many researchers carried out a study on the physical and
mechanical properties, and the correlation between the particular features of agricultural products
among others was: Bart P. et al.[2], Nicolas N. et al.[3], and Ha et al.[4] studied physical and
mechanical properties of cocoa bean; Karaj et al.[5] carried research on physical, mechanical, and
chemical properties of *Jatropha curcas*; Keramat et al.[6] studied on physical properties of date fruit;
Jaliliantabar et al.[7] studied on physical properties of Kumquat; Zare, D. et al. [8] studied on some
physical and mechanical properties of Russian olive fruit; Loghavi, M. et al.[9] studied physical and
mechanical properties of Almond; Tunde-Akintunde, T.Y. et al.[10] studied some physical properties
of Sesame Seed; Altuntas, E. et al.[11] studied some physical properties of Fenugreek; Celik A et
al.[12] studied some physical, pomological and nutritional properties of Kiwifruit; Dursun, I. et
al.[13] studied some physical properties of sugarbeet seed; Eke, C. N. U., et al. [14] studied some
physical properties of Jackbean seed, and Sessiz, A. et al.[15], Amer E. A.H., et al.[16], Yalcin, H.
[17], and Kaveri, G., et al.[18] studied physical and mechanical properties of Onion.

Some researchers who had researched the physical and mechanical properties of coffee bean were
Iván Darío, I.A.T., et al.[19], Couto, S.M., et al.[20], Marija R. J., et al.[21], and Coradi, P.C. et
al.[22]. Most of the coffee bean studies related to fresh cherry, hulled and unhulled coffee bean. The
reviews on dried coffee cherry resulting from the natural process were relatively rare.

According to the previous study, physical and mechanical properties were useful parameters for the
development of the design and manufacture of coffee cherry processing equipment, i.e., shape and size
were essential parameters in the screening as well as grading and evaluating the quality of the
products. In the hulling mechanism, the size of the dried cherry resulting from the natural system was
essential to set the steel huller component clearance [23]. The Surface area and geometric diameter
played a significant role in the drying process and were also essential for the determination of terminal
velocity, the coefficient of drag and Reynolds number [24]. The mass was a necessary parameter in the
calculation of densities, and it could determine the quality of materials; the volume also played a role
required in the roasting process where roasting made the beans expanded [25]. The hardness was
essential in evaluating their feeding value as well as their size reduction and milling characteristics,
and Fracture force was also necessary for equipment design such as the crusher. Both emptying and
filling angle of repose can determine the behavior of materials flow [26], the angle of repose has also
used in equipment design and storage structures [24].

The Study aimed to analyze the physical and mechanical properties, to determine the relationship
in-between the properties component of the dried cherry.

2. Materials and methods

2.1. Material Preparation

The fresh Robusta cherry sample collected from Cupunagara village (Latitude 6°46'57.71 "S,
Longitude 107°41'37.15" E, and elevation 1153 MAMSL), Cisalak sub-district, Subang district, West
Java province. The sample then dried using electrical drier at temperature 50 °C for 72 hours.

The size features in this study consisted of polar diameter (Dp), equatorial diameter (De), thickness
(t), arithmetic (Dam), and geometric diameter (Dgm). The shape consisted of shape index (SI) and
sphericity (ψ). The area features consisted of a cross-sectional of t (Acs), frontal surface area (Afs),
and total surface area (As). The physical properties included mass (m), volume (v), particle (ρp) and
bulk (ρb) densities. The mechanical properties consisted of emptying (θe) and filling (θf) angles of
repose, friction (μ), Hardness (H) and fracturablity (frac).
Instruments used for measuring the sample consisted of digital vernier caliper with an accuracy 0.01 mm, an electronic balance with an accuracy 0.1 gram, an analytical balance with an accuracy 0.01 mg, an apparatus to determine angle of repose and static friction, a texture analyser, a beaker glass and a graduated cylinder and high-quality colorimeter NH 310 and cabinet electric drier.

The statistical package programmes, i.e., descriptive statistics, One-Sample Kolmogorov-Smirnov Test, matrix correlation, stepwise regression analysis, and pair sample test performed to assess the characteristic and relationship among the size, shape, area, physical and mechanical properties.

2.2. Moisture content
The water content was calculated by the following equation [27]:

\[
M_{wb} = \frac{W_1 - W_2}{W_1} \times 100% \tag{1}
\]

Where: \(M_{wb}\): Moisture content, % wet basis; \(W_1\): The initial weight of the sample, gram \(W_2\): The final weight of the sample, gram

2.3. Geometric
2.3.1. Size
Size comprised of polar diameter, equatorial diameter, thickness, arithmetic diameter and geometric diameter, polar and equatorial diameter, and thick of samples measured by using a digital vernier caliper with an accuracy of 0.01 mm. There were many researchers had measured these dimensions of agricultural products similarly, among them were Shoba H., et al. [28], Mukesh D et al. [29], Kaveri [18], Vijaya & Srivastava [30], and Bahnasawy et al. [31], had measured these dimensions for onion bulbs, Karaj et al. [5] had measured these dimensions for Jatropha curcas, Dursun I., et al. [13] had measured these dimensions for sugar beet seed, Despande S.D. et al. [32] had mastered these dimensions for soybean, Mohsenin [24] and Shepherd & Bhardwaj [33] had measured these dimensions for other grains and seeds.

Geometric diameter is the cube root of the product of linear dimensions of polar diameter, equatorial diameter, and thickness. Referring to Mohsenin [24], Bahnasawy et al. [31] and Kaveri et al. [18], the geometric mean diameter determined using equation (2). The arithmetic diameter is the sum of all the three linear dimensions, i.e., polar diameter, equatorial diameter, and thickness of the sample divided by the total number of linear dimensions [31]. The arithmetic diameter calculated using equation (3).

\[
D_{gm} = \sqrt[3]{D_p \times D_e \times t} \tag{2}
\]

\[
D_{am} = \frac{D_p + D_e + t}{3} \tag{3}
\]

Where: \(D_{gm}\): Geometric diameter, mm; \(D_{am}\): Arithmetic diameter, mm; \(D_p\): Polar diameter, mm; \(D_e\): Equatorial, mm; \(t\): Thickness, mm

2.3.2. Shape
Shape and size were essential parameters in the screening as well as grading and evaluating the quality of the products. In the hulling mechanism, the size of the dried cherry resulting from the natural system was essential to set the steel huller component clearance [23]. The shape which comprised of shape index and sphericity is an essential parameter in grading to develop the quality of the product such as coffee cherry, or coffee bean. Shape consisted of the shape index and sphericity. The shape index is the ratio of the equatorial diameter and root square of the product of polar and thickness of samples [31]. The shape index used to evaluate the shape of the dried cherry and calculated according to equation (4).

\[
SI = \frac{D_e}{\sqrt{D_p \times t}} \tag{4}
\]

Where: \(SI\): Shape index, \(D_p\): Polar diameter, mm; \(D_e\): Equatorial, mm; \(t\): Thickness, mm
The sphericity of the dried cherry is the ratio of the root of the product of equatorial diameter, polar diameter, and thickness of dried cherry and its equatorial diameter[9]. The sphericity calculated using equation (5) as follows:

\[ \psi = \frac{3D_e \times D_p \times t}{D_e} \]  

(5)

Where : \( \psi \): Shape index; \( D_p \): Polar diameter, mm; \( D_e \): Equatorial, mm; \( t \): Thickness, mm

2.3.3. Area of dried Robusta cherry

Surface area and geometric diameter played a significant role in the drying process and were also essential for the determination of terminal velocity, the coefficient of drag and Reynolds [24]. The area of the dried Robusta cherry determined through the frontal surface, cross-section and total surface areas of the dried Robusta cherry[31]. The frontal surface area is the representation of a solid object appeared if cut by a plane, while the cross-sectional area is the area of the section made by a plane cutting an object transversely to the longest axis.

The frontal surface area (\( A_{fs} \)), cross-sectional area (\( A_{cs} \)) and total surface area (\( A_s \)) calculated using equation (6), (7), and (8) respectively.

\[ A_{fs} = \frac{\pi}{4} D_e D_p \]  

(6)

\[ A_{cs} = \frac{\pi}{4} x \left( \frac{(D_e+D_p+t)^2}{9} \right) \]  

(7)

\[ A_s = \pi (D_{gm})^2 \]  

(8)

Where : \( A_{fs} \): Frontal surface area, mm\(^2\); \( A_{cs} \): Cross-sectional area, mm\(^2\); \( A_s \): Total surface area, mm\(^2\); \( D_e \): Equatorial diameter, mm; \( D_p \): Polar diameter, mm; \( t \): Thickness, mm; \( D_{gm} \): Geometric mean diameter, mm; \( \pi \): Constant, 3.14

2.4. Physical properties

The physical properties included four features viz. mass, volume, particle and bulk densities[31]. The mass was an essential parameter in the calculation of densities, and it could determine the quality of materials. The volume also played a necessary role in the roasting process where roasting made the beans expanded [25]. The weight (\( m \)) of dried cherry samples measured by using an electronic balance with an accuracy of 0.01 gram. The volume (\( v \)) of dried cherry samples determined by the water displacement method. Particle density is the ratio of mass in grams and the amount of displacement water in cm\(^3\). The particle density calculated according to equation (9). The bulk density is the proportion of weight in a specific volume, calculated based on formula (10).

\[ \rho_p = \frac{m}{v} \text{gr/cm}^3 \]  

(9)

\[ \rho_b = \frac{m_{500}}{v_{500}} \text{gr/cm}^3 \]  

(10)

Where: \( \rho_p \): Particle density, gr/cm\(^3\), \( \rho_b \): Bulk density, gr/cm\(^3\), \( m \): Mass, gram, \( v \): Volume, cm\(^3\), \( m_{500} \): Mass of 500 cm\(^3\) sample, gram, \( v_{500} \): The Volume of 500 cm\(^3\)

2.5. Mechanical properties

The mechanical properties measured comprised of five features viz. hardness, fracturability, emptying angle of repose, filling angle of repose and friction. Hardness value is the peak force that occurred during the first compression; therefore the hardness of agricultural product such as cherry or bean coffee is essential in evaluating their feeding value as well as their size reduction and milling characteristics. Fracturability is the force at the first high spot which will determine the maximum strength which applied to a material without damaging the product. Fracture force is also necessary for equipment design such as the crusher. Hardness and fracturability measured using TA XT plus Texture Analyser Stable Micro System. In general, both emptying and filling angle of repose can
determine the behavior of materials flow [26]. Therefore, the angle of repose has also used in equipment design and storage structures [24]. The emptying angle of repose ($\theta_e$) measured by an apparatus consisting of a sloping platform with adjustable angles [34]. The filling angle of repose ($\theta_f$) measured by PVC cylinder (10 cm x 10 cm) in which this cylinder filled with the cherry sample, and then the barrel was lifted gradually until the cherry formed a cone [35] and Pradhan, R.C. et al. [36].

Practically coefficient of friction used in designing agricultural equipment, bins, silos, and other storage and handling structures [24]. The coefficient of friction measured by using a PVC cylinder (diameter 10 cm, height 5 cm) which placed on the friction surface. The PVC cylinder filled with the cherry sample then lifted around 3 mm from the friction surface so that the barrel did not touch the friction surface. The friction surface lifted gradually until the cylinder started to slide down. The angle ($\theta$) between the elevated friction surface and the horizontal surface is known as the angle of static friction between the sample and the friction surface [2], [36]. Measurement of emptying and filling angle of repose and friction performed on various surfaces of materials, i.e., stainless steel 1 mm, aluminum 1 mm, acrylic 3 mm, and plywood 18 mm. The emptying angle of repose, filling angle of repose and friction calculated according to equation (11), (12) and (13) respectively.

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

$$\theta_f = \tan^{-1} \left( \frac{2h}{D} \right) \quad (12)$$

$$\mu_s = \tan \theta \quad (13)$$

Where: $\theta_e$: Emptying angle of repose; $\theta_f$: Filling angle of repose; $h_1$: The Initial height of the platform; $h_2$: The Final height of the platform; $h$: Height of cone; $x_1$: Distance of $h_1$; $x_2$: Distance of $h_2$; $D$: The diameter of the cone; $\mu_s$: Static Friction

3. Results And Discussion

All the properties of the dried robusta coffee cherry assessed at an average moisture content of 14.80±2.29 %. Results of measurements of size, shape, area and physical properties presented in Table 1.

| Parameters | Minimum | Maximum | Mean | Std. Deviation |
|------------|---------|---------|------|----------------|
| Dp         | 11.10   | 15.15   | 12.87| 0.96           |
| Dc         | 9.92    | 12.41   | 11.04| 0.65           |
| $t$        | 8.81    | 11.46   | 9.75 | 0.60           |
| Dam        | 10.36   | 12.57   | 11.22| 0.56           |
| Dgm        | 10.35   | 12.50   | 11.14| 0.55           |
| $\psi$     | 0.77    | 0.93    | 0.87 | 0.04           |
| shape      | 0.52    | 1.07    | 0.78 | 0.15           |
| Acs        | 45.02   | 91.99   | 67.92| 12.95          |
| Af$\delta$ | 39.10   | 79.24   | 58.98| 11.89          |
| As         | 336.34  | 490.57  | 390.47| 39.00          |
| $m$        | 0.38    | 0.56    | 0.48 | 0.05           |
| $v$        | 0.58    | 1.02    | 0.73 | 0.11           |
| pp         | 0.45    | 0.92    | 0.68 | 0.13           |
| pb         | 0.42    | 0.48    | 0.45 | 0.016          |

The One-Sample Kolmogorov-Smirnov test of the geometric, physic and mechanic of the sample indicated that the data frequently scattered. The normal distribution of geometrical, physical and mechanical properties indicated by the value of asymptotic signficance 2-tailed more than 0.05 (p>0.05). The result of matrix correlation analysis of the sample showed that polar diameter, equatorial diameter, thickness, arithmetic diameter, geometric diameter, and total surface area were dependent on volume. The cross-section area, frontal surface area, and shape index were dependent on particle density. The sphericity was dependent on bulk density. The relationship between the geometric and physical properties of the sample in detail presented as follows:
\[ D_p = 6.931v + 8.215 \quad R = 0.738 \quad \text{SEE} = 0.6576 \]
\[ D_e = 4.497v + 7.762 \quad R = 0.761 \quad \text{SEE} = 0.4313 \]
\[ t = 4.196v + 6.690 \quad R = 0.775 \quad \text{SEE} = 0.3849 \]
\[ D_{om} = 5.025v + 7.558 \quad R = 0.994 \quad \text{SEE} = 0.0639 \]
\[ D_{om} = 4.969v + 7.518 \quad R = 0.999 \quad \text{SEE} = 0.0306 \]
\[ \Psi = 1.153\rho_b + 0.350 \quad R = 0.437 \quad \text{SEE} = 0.0378 \]
\[ S_i = 1124\rho_p + 0.021 \quad R = 0.959 \quad \text{SEE} = 0.4397 \]
\[ A_{cs} = 99.374\rho_p + 0.477 \quad R = 1.000 \quad \text{SEE} = 0.2852 \]
\[ A_{fs} = 88.230\rho_p - 0.903 \quad R = 0.967 \quad \text{SEE} = 3.0929 \]
\[ A_s = 352.666v + 133.609 \quad R = 0.999 \quad \text{SEE} = 1.3856 \]

Table 2 showed the texture profile, i.e., hardness and fracturability of the sample. The result of the matrix correlation showed that there was a weak relationship between the hardness and fracturability.

Table 2. Descriptive Statistics of hardness and fracturability

|     | Minimum | Maximum | Mean  | Std. Deviation |
|-----|---------|---------|-------|----------------|
| H   | 2.41    | 5.54    | 3.88  | 0.98           |
| F_{fract} | 0.76 | 2.00    | 1.23  | 0.44           |

The relationship between the hardness and fracturability was as follow:

\[ H = 0.208F_{fract} + 3.623 \quad R = 0.094 \quad \text{SEE} = 1.0362 \]

Table 3 showed the value of emptying and filling repose of angle, and the static friction of the sample on various surfaces. The emptying angle of repose on multiple surfaces showed a similar pattern with filling angle of repose and static friction, the more significant of the emptying angle of repose the more considerable filling angle of repose and static friction.

Table 3. Descriptive Statistics of Emptying Angle of Repose and Static Friction on various surfaces

|     | Minimum | Maximum | Mean  | Std. Deviation |
|-----|---------|---------|-------|----------------|
| \( \theta_e \)_{ACRY} | 15.10   | 18.41   | 16.64 | 0.83           |
| \( \theta_e \)_{SS}   | 13.86   | 19.52   | 17.03 | 1.43           |
| \( \theta_e \)_{AL}   | 14.55   | 22.76   | 18.46 | 2.26           |
| \( \theta_e \)_{PLYW} | 16.83   | 20.97   | 18.76 | 1.23           |
| \( \mu \)_{ACRY}     | 0.22    | 0.39    | 0.28  | 0.04           |
| \( \mu \)_{SS}       | 0.21    | 0.33    | 0.28  | 0.03           |
| \( \mu \)_{AL}       | 0.25    | 0.38    | 0.31  | 0.04           |
| \( \mu \)_{PLYW}     | 0.29    | 0.47    | 0.36  | 0.05           |
| \( \theta_f \)_{ACRY} | 12.52   | 19.15   | 15.83 | 1.67           |
| \( \theta_f \)_{SS}  | 13.09   | 26.81   | 17.89 | 3.03           |
| \( \theta_f \)_{AL}  | 15.05   | 22.72   | 19.24 | 1.65           |
| \( \theta_f \)_{PLYW} | 12.32   | 26.48   | 19.91 | 3.15           |

The biggest emptying angle of repose, filling angle of repose and static friction occurred on the surface plywood followed by aluminum, stainless steel, and acrylic. Results of matrix correlation analysis showed that there was a relationship between static friction of the sample on a certain surface and its emptying angle of repose; otherwise, there was no correlation between that and the filling angle of repose. The regression equations between the static friction and emptying angle of repose of each surface were as follows:

\[ \mu_{ACRY} = 0.034\theta_e-0.280 \quad R = 0.772 \quad \text{SEE} = 0.0233 \]
\[ \mu_{SS} = 0.016\theta_e+0.016 \quad R = 0.700 \quad \text{SEE} = 0.0232 \]
\[ \mu_{AL} = 0.016\theta_e+0.017 \quad R = 1.000 \quad \text{SEE} = 0.0003 \]
\[ \mu_{PLYW} = 0.035\theta_e-0.035 \quad R = 0.930 \quad \text{SEE} = 0.0175 \]
4. Conclusion
The results of this work found that there was a robust correlation between polar diameter, equatorial diameter, thickness, geometrical diameter, arithmetic diameter surface area and the volume with a correlation coefficient of 0.738, 0.761, 0.775, 0.994, 0.999 and 0.999 respectively. The strong correlation also occurred in the relationship between the sphericity, shape index, cross-sectional area, frontal surface area and the particle density with the correlation coefficient of 0.959, 1.00 and 0.967 respectively. The sphericity had a moderate correlation with bulk density; its correlation coefficient was 0.437. The hardness of the sample showed a weak correlation with the fracturability; its correlation coefficient was 0.094. The static friction had a strong association with the emptying angle of repose but not with filling angle of repose. The determination value of the relationship between static friction and emptying angle of repose of acrylic, stainless steel, aluminum, and plywood were 0.772, 0.700, 1.000 and 0.930 respectively.

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