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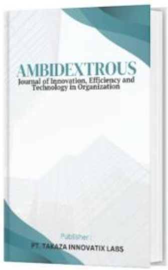

Physical Properties of Cacao Beans

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Abstract: *The Cacao beans are widely used as raw material in the chocolate and food industries, where knowledge of their physical properties is essential for post-harvest handling and processing. This study aimed to compare the physical characteristics of mature and raw cacao beans by determining major diameter (Dmajor), moderate diameter (Dmoderat), minor diameter (Dminor), geometric mean diameter (GMD), sphericity, volume, bulk density, angle of repose, and angle of friction. The research was conducted through direct observation and measurement of cacao bean samples in both maturity levels. Data were analyzed by calculating dimensional and physical parameters using standard formulas. The results indicated that mature cacao beans generally had larger dimensional values (Dmajor, Dmoderat, Dminor, and GMD) compared to raw beans, which directly influenced their volume and sphericity. Bulk density of raw beans was relatively higher, while mature beans showed lower density due to reduced moisture content. Furthermore, the angle of repose and angle of friction were higher in raw beans, reflecting stronger resistance to flow and surface contact compared to mature beans. In conclusion, maturity level significantly affects the physical properties of cacao beans, which has implications for their handling, drying, and processing in the cacao industry.*

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Introduction

Indonesia's plantation sector plays a crucial role in the national economy, relying on several superior commodities marketed internationally. One of the main commodities featured in the plantation sector is cocoa. Cocoa beans also play a role in driving regional development and agro-industry development. The Indonesian Cocoa Council (Dekaindo) also stated that Indonesia ranked third in the world as the largest cocoa producer after Ivory

Coast and Ghana in 2013 and has received recognition and officially joined the International Cocoa Council Organization (ICCO). Based on data on cocoa production in Indonesia, domestic demand for cocoa is still relatively small compared to total cocoa production. Cocoa demand can be seen based on the level of consumption and community needs in a country. Indonesia's high total cocoa production compared to low domestic demand means that most cocoa production is intended for export (Puspita et al., 2018).

Indonesia is one of the largest cocoa producers in the world. According to the International Cocoa Organization (ICCO), Indonesia can produce 200,000 tons of cocoa beans annually. According to Statistics Indonesia (BPS), Indonesia produced 577,038 tons of cocoa beans in 2018 (Widhiyoga & Wijayati, 2022). Cocoa is a plantation commodity with significant potential for increasing the country's foreign exchange. The total cocoa plantation area in Indonesia in 2017 was 1.72 million hectares, approximately 63.88% of which was produced by the five central cocoa plantation provinces: 16.83% (Central Sulawesi), 14.94% (Southeast Sulawesi), 14.26% (South Sulawesi), 9.22% (West Sumatra), and 8.63% (West Sulawesi) (Ariningsih et al., 2021).

The fluctuating price of cocoa is influenced by the quality of beans which is currently less noticed by farmers, low quality due to the ability of farmers who are still considered lacking in applying technology to cocoa cultivation on plantations, and generally cocoa plants from farmers are plants that are decades old, so they are not very productive, so this problem is quite complex, this can cause cocoa prices to continue to decline because the number and size of beans also decrease, while maintenance costs for cocoa cultivation continue to increase (Kusmiah et al., 2020).

To date, cocoa in Indonesia remains an export commodity in the form of beans, accounting for approximately 83%. Indonesian cocoa is still of low quality, especially those produced by smallholder plantations. Generally, cocoa beans traded at the farmer level in South Sulawesi are unfermented. Furthermore, farmers generally do not sort them either before breaking the cocoa pods or after drying. The cocoa beans are sold directly to collectors, resulting in prices far below market prices. This is due to strong buyer dominance and a weak bargaining position for farmers (Hadinata & Marianti, 2020). One cause of the low quality of cocoa beans is the processing process in Indonesia. Indonesian cocoa beans are rarely fermented first, even though fermented cocoa beans are of better quality than unfermented cocoa beans (Ariyanti, 2017).

Fermentation of raw cocoa beans occurs in two stages: the first involves microbial reactions occurring in the pulp and outer layers of the bean; the second phase involves several hydrolytic reactions occurring within the cotyledons. The aromatic quality of chocolate requires the use of cocoa with a high aromatic potential, which is achieved during cocoa bean fermentation. Traditional fermentation is still often carried out on a small scale with strains of yeast and acetic acid bacteria and under poorly controlled conditions, resulting in highly variable cocoa quality (Kouamé et al., 2021). Post-harvest cocoa bean processing, such as fermentation, not only determines the formation of aroma and flavor compounds but also plays a role in the formation of bioactive compounds beneficial to

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health (Domínguez-Pérez et al., 2020). Microbial strains involved in spontaneous fermentation can originate from direct manipulation of the cocoa beans, such as workers' hands, tools used during post-harvest processing, insects, banana leaves, piles, boxes, baskets, trays or platforms directly, or the surface of the beans. However, not all microorganisms will participate during cocoa bean fermentation (Coronado et al., 2019).

Physical properties are characteristics of a material that can be measured or observed without changing its chemical composition, such as dimensions, mass, volume, density, sphericity, porosity, and flow behavior such as angle of repose and angle of friction (Timumu et al., 2022). Given the importance of knowledge about the physical properties of agricultural products starting from the time of harvesting, transportation, design and dimensions of storage space, manufacture and operation of process equipment are the main considerations for conducting this research. Drying also allows for physical changes, biochemical behavior, and ultimately affects the quality of the dried product. This study aims to study the effect of drying temperature on changes in the physical properties of non-fermented cocoa beans (Sri Waluyo & Permatahati, 2023).

The quality of cocoa beans at PTPN XII Kendenglembu Plantation, Banyuwangi is still considered quite good, so the quality of bulk cocoa beans can be improved by fermentation and drying processes. Through the fermentation process, bulk cocoa beans will form flavor precursors, reduce bitterness, change the color to blackish brown, enhance the aroma of cocoa and nuts, and harden the seed coat to become like a shell (Jawad et al., 2018). According to Sinaga and Dersial, 2016, knowledge of the physical properties and characteristics of materials is very necessary in modern agriculture, especially the processing of agricultural materials (Sinaga, 2016).

Cocoa beans possess unique characteristics based on genetics, origin, certification, and flavor (Santander Muñoz et al., 2020). Classifying cocoa beans according to their size is relevant in confirming their chemical composition, including fat content, moisture content, pH, and total free fatty acids. The larger the cocoa bean, the higher the amount of fat produced (Sabahannur et al., 2023). Drying plays a role in releasing water from the beans, thus preventing mold growth during storage and extending the shelf life of dried cocoa beans. The basic principle of the drying process is the evaporation of water content in the material into the air, which has a lower water content than the material. The transfer of water mass is characterized by a reduction in the material's mass and a change in its physical form (Luqman Ramadhani et al., 2023).

Research Methods

The materials used in this study consisted of 500 grams of ripe cocoa beans and 500 grams of raw cocoa beans as the primary samples. The tools used to support the research included vernier calipers for dimensional measurements, PVC pipe and plywood as test components, iron plates as supporting construction materials, and a ruler and protractor for additional measurements. Additionally, an analytical balance was used to obtain accurate

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sample weight data.

Place and Time

This research was conducted on October 1, at 8.30 – 11.00, at the Agricultural ICT LAB, Jambi University

Research methods

1. Sample Preparation

Before laboratory testing, the cocoa beans were dried in the sun for 3–5 days. The samples used consisted of 500 grams of ripe cocoa beans and 500 grams of raw cocoa beans.

2. Cocoa Bean Dimension Measurement

Cocoa bean dimensions were measured to determine their physical dimensions, including major dimensions (d major), moderate dimensions (d moderate), and minor dimensions (d minor). Measurements were taken using a caliper on 5 ripe and 5 raw cocoa beans.

3. Determining the Angle of Repose

Determining the stack angle is done using the following procedure:

a. Weigh the empty tube/pipe, then measure the height and diameter of the tube using a vernier caliper.
b. Put the ripe and raw cocoa beans into the tube until it is full, then weigh it using an analytical balance to find out the mass of cocoa beans in the tube.
c. Measure the depth of the tube filled with cocoa beans from the top surface to the bottom of the tube using a vernier caliper.
d. Place the tube containing the cocoa beans on a flat surface, then lift the tube until the cocoa beans fall to form a mound.
e. Measure the furthest distance the cocoa beans fall using a ruler, the height of the mound using a vernier caliper, and the angle of the mound using a protractor.

4. Determining the Angle of Friction

Determining the Angle of Friction is done using plywood and iron plates with the following steps:

a. Prepare 5 ripe cocoa beans and 5 raw cocoa beans each.
b. Place the cocoa beans on the end of the plywood, then lift the plywood slowly until the cocoa beans start to fall.
c. When the cocoa beans start to move or fall, the lifting is stopped, then the angle of inclination of the plywood is measured using a protractor.
d. The process is carried out separately for ripe and raw cocoa beans. The same applies to the iron plates.

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Results and Discussion

Based on the results of dimensional measurements (Table 1 and Table 2), ripe cocoa beans have average major, moderate, and minor dimensions of 1.269 mm; 1.197 mm; and 0.733 mm, respectively. Meanwhile, raw cocoa beans show average major, moderate, and minor dimensions of 1.884 mm; 1.129 mm; and 0.955 mm, respectively. These data indicate that raw cocoa beans tend to have larger sizes in major and minor dimensions than ripe cocoa beans. Therefore, the level of maturity can affect the size and shape of the beans due to changes in water content and the internal structure of the beans.

Table 1. Measuring the Dimensions of Ripe Cocoa Beans

Material	mayor	moderate	ruler
U1	0.036	1,105	0.094
U2	0.805	1.11	0.74
U3	2,435	1,125	0.615
U4	2.14	1,325	0.74
U5	1.93	1,325	0.63
Average	1,269	1,197	0.733

Table 2. Measurement of Raw Cocoa Bean Dimensions

Material	mayor	moderate	ruler
U1	2,115	1,205	0.45
U2	1,815	1.11	0.605
U3	2,125	1.3	0.315
U4	1,525	0.92	3,015
U5	1.84	1.11	0.41
Average	1,884	1,129	0.955

Table 3.GMD, Sphericity, , Tube Volume

Criteria	Amount
GMD	0.677
Sphericity	0.367
Volume of the Cylinder	599.53

In the calculation of GMD, sphericity, and cylinder volume (Table 3), the GMD value obtained was 0.677 mm with a sphericity of 0.367. A low sphericity value indicates that the shape of the cocoa beans is not close to perfectly round, but rather more oval or flat. These results are consistent with research by Wulandari et al. (2022) who reported that cocoa beans generally have an oval shape with a sphericity below 0.7.

Table 4. Bulk Density

Bulk Density	Amount
Ripe Cocoa Beans	0.743
Raw Cocoa Beans	0.463

The bulk density value (Table 4) shows that ripe cocoa beans have a bulk density of 0.743 g/cm³, higher than raw cocoa beans at 0.463 g/cm³. This difference is thought to be caused by differences in water content, where raw beans have a higher water content so that the interparticle space is larger and reduces the bulk density.

Table 5. Angle of Repose

Criteria	Ripe Cocoa Beans	Raw Cocoa Beans
Mound Height	4.7	2.5

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Slope	21.40	9.54

The results of the angle of repose measurements (Table 5) show that ripe cocoa beans have a mound height of 4.7 cm with a slope angle of 21.40°, while raw cocoa beans have a mound height of 2.5 cm with a slope angle of 9.54°. The higher mound angle value in ripe cocoa beans indicates that the flowability of ripe beans is lower than that of raw beans. The greater the angle of repose value, the less likely the material is to flow.

(a) (b)

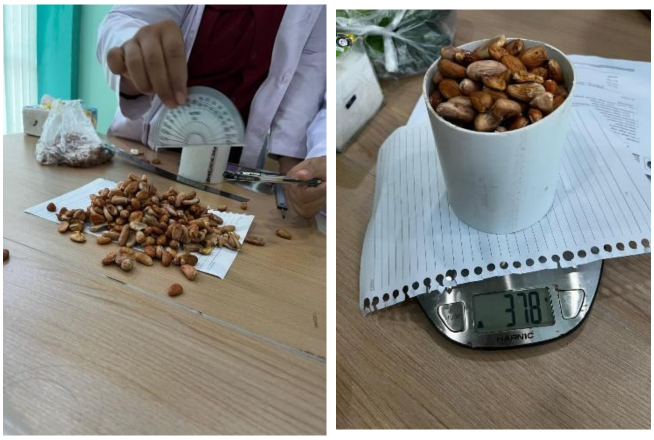

Figure 1. (a) measuring the slope (b) weighing the mass of ripe cocoa beans

Table 6. Angle of Friction

Criteria	Ripe Cocoa Beans	Raw Cocoa Beans
Iron plate	40°	50°
Plywood	55°	60°

Furthermore, in the angle of friction test (Table 6), it was found that ripe cocoa beans had a friction angle of 40° on the iron plate and 55° on the plywood, while raw cocoa beans had 50° and 60°, respectively. This indicates that raw cocoa beans have a higher friction force than ripe beans, so they require a greater angle of inclination to be able to move. A high friction angle value indicates a stronger surface interaction, which is likely caused by the surface texture of raw beans which is still moist, thus increasing the adhesion force to the media.

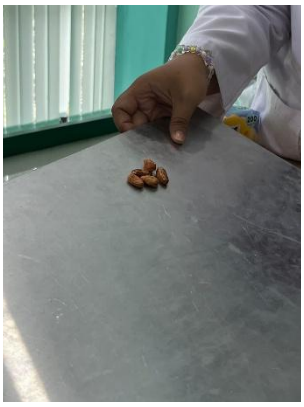

Figure 2. Measuring angles using an iron plate

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Overall, the results of this study confirm that the level of ripeness significantly affects the physical properties of cocoa beans. Raw cocoa beans have a smaller size, lower bulk density, and a higher friction angle than mature beans. Conversely, mature beans have a higher bulk density and stack angle, but smaller dimensions. These differences in physical properties are important to consider because they will impact the drying process, transportation, and design of cocoa bean processing machines.

Conclusion and Recommendation

The results showed that the level of maturity significantly affected the physical properties of cocoa beans. Ripe cocoa beans had moderately larger dimensions than raw beans, while raw cocoa beans tended to be larger in both major and minor dimensions. Geometric Mean Diameter (GMD) and sphericity values indicated that both types of beans were oval in shape with a low degree of sphericity. The bulk density of ripe cocoa beans was higher (0.743 g/cm^3) than raw (0.463 g/cm^3), indicating that ripe beans were denser. The angle of repose of ripe cocoa beans was greater (21.40°) than raw (9.54°), so ripe beans had lower flowability. Conversely, the angle of friction of raw cocoa beans was higher (50°–60°) than ripe beans (40°–55°), indicating a greater frictional force due to the higher water content. Overall, ripe cocoa beans were denser and less flowable, while raw cocoa beans were larger in size but had a lower density and higher friction.

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