Physical characteristics of chocolate made from cocoa bean fermented at different duration: a preliminary study

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Abstract. Dark chocolate is one of the most popular chocolates due to its health benefit offered. One of the factors influencing its health effect is the fermentation process prior to the chocolate making. Fermentation change the cocoa bean chemical compound and affected the flavor and antioxidant content. Aside from that, changes in the inner structure of cocoa nib may also occur, resulting in different characteristics of cocoa solids. The aim of this study was to do a preliminary study on the impact of fermentation level (unfermented, half-fermented, and fermented cocoa bean) on the quality attributes of dark chocolate, namely color, glossiness, melting point and particle size. The results showed that fermentation duration influenced the characteristics of chocolate, to some extent. The color of chocolate made from fermented bean exhibited higher \(L^*\), \(C^*\), \(h^o\) values than chocolate made from half-fermented and unfermented cocoa bean, consecutively. On the other hand, melting point of chocolate made from unfermented cocoa bean had higher propensity than that of chocolate made from half-fermented and fermented bean. Glossiness and particle size of the chocolates were comparable.

1. Introduction
Cacao is the main ingredients for chocolate production. Cacao is harvested from cacao three \((\textit{Theobroma cacao L})\) [1]. Indonesia is the 5\(^{th}\) biggest cacao producer in the world, with cocoa bean production of 240,000 tons [2]. With land area of approximately 1.66 million hectares, Indonesia has succeeded in producing cocoa with an average national productivity of 737 kg / hectares [3]. This shows that cacao is one of Indonesia’s important commodities.

The quality of Indonesian cocoa bean is relatively low since most of the farmers do not ferment their bean. The fact that 97.29% cocoa in Indonesia is managed and/or owned by farmer, creating difficulties to ask them to ferment their beans [3]. The main aim of fermentation is to form aroma precursors, reducing the sourness and astringency as result of oxidation and polymerization of phenolic compounds [1,4,5,6]. After fermentation, due to the hydrolysis of phenolic compound by glycosidase, the color of cocoa bean changes [7].
Fermentation is usually carried out for 5-6 days for Forester variety and 1-3 days for Criollo variety. Variations in fermentation duration cause differences in the chemical characteristics of the final product, such as acidity [5,8,9]. Visually, the difference between fully fermented and unfermented cocoa beans can be seen from the color. Fully fermented cocoa beans have dark brown color, while unfermented cocoa beans tend to have dark gray color [10,11].

As a result of the fermentation process, the internal structure of the cocoa beans undergoes changes which can result in different characteristics of cocoa solids [12,13]. The internal structure of the beans becomes more brittle, in contrast to the dense unfermented beans without cavities [12,14].

Dark chocolate is produced from sugar and cocoa solids which are dispersed in cocoa butter with or without the addition of lecithin [1,15,16]. Sugar and cocoa solids are bulky materials, affecting many characteristics of chocolate, such as appearance, flow properties, etc [17,18]. Therefore, the characteristics of sugar and cocoa solids highly influence the characteristics of the chocolate made. Several researches on the influence of sugar have been done. However, to the best our knowledge, there is no research investigating the structure of the cocoa solids, as a result of fermentation duration, on the quality attributes of chocolates. Hence, the aim of this work was to do a preliminary study on the impact of fermentation duration on the quality attributes of chocolate, namely appearance (color and glossiness), melting point, and particle size.

2. Materials and methods

This research was conducted at the Laboratory of Food and Postharvest Engineering and Laboratory of Biophysics, Faculty of Agricultural Technology, Universitas Gadjah Mada. The materials used consist of cocoa mass made from fermented cocoa beans (6 days of fermentation), half fermented cocoa beans (3 days of fermentation), and unfermented cocoa beans obtained from Pawon Gendis, Kulon Progo. Sucrose was purchased at local supermarket in Yogyakarta. The moisture content of the beans is shown in Table 1.

| Ingredients       | Moisture Content (%) |
|-------------------|----------------------|
| Cocoa mass (F)    | 1.29±0.10            |
| Cocoa mass (HF)   | 1.18±0.10            |
| Cocoa mass (NF)   | 1.09±0.16            |

F: Fermented beans; HF: Half-fermented beans; NF: Unfermented / non-fermented beans

2.1. Sample preparation

Dark chocolate was made with a composition of 70% cocoa and 30% sugar. Chocolate was produced using a melanger (Wonder Premier Grinder) with a grinding time of 10 hours. Tempering was done manually using an oven. The tempering process began with heating the chocolate until it reached a temperature of 50 °C followed by stirring and holding time for 9 minutes. Afterwards, the temperature was slowly decreased with the help of ice water until the chocolate paste reached a temperature of 32 °C. This process continued until a temperature of 27 °C. At this point, the temperature was maintained for 9 minutes. This cooling process was carried out at a room temperature. At the end of the tempering process, the chocolate temperature was raised to a temperature of 32 °C.

The tempered chocolates were poured into a 13 cm x 3 cm x 0.5 cm mold and then vibrated for 3 minutes using a vibrating table to release air bubbles. The final product was immediately cooled at 12 °C for 1 hour. After 1 hour, the chocolate bars were demolded and stored at 20 °C. The analyses were done on day 1, 4, 7, 10, and 13 in three replications.
2.2. Analytical methods

2.2.1 Color. Color test was carried out using a Chromameter (Minolta CR-400). The instrument was calibrated using a reference standard before measurement. Color parameters were expressed in the CIELAB system. L * indicates lightness, ranging from 0 (black) to 100 (white), a * indicates green to red levels, ranging from +60 (red) to -60 (green), and b * indicates blue to yellow levels, ranging from +60 (yellow) to -60 (blue). From these values, L* C* h° were calculated according to the equation 1 and 2 [16].

\[ h^° = \arctan \left( \frac{b^*}{a^*} \right) \]  
\[ C^* = \left[ (a^*)^2 + (b^*)^2 \right]^{1/2} \]  

2.2.2 Glossiness. Determination of the glossiness value was done manually by reflecting white light on the surface of the chocolate. The gloss level, determined by trained panelist, was based on a scale of 1 as the lowest value to 10 as the highest value.

2.2.3 Melting point. Melting point of chocolate was manually determined in a water bath (Advantec model TBX272DA). Chocolate with the size of 1x1 cm was put in a plastic spoon that was assembled in such a way. The spoon was then put in a 250 ml beaker filled with water (150 ml) and heated in the water bath. The initial temperature of the water bath was conditioned at 28 °C. After the water temperature in the beaker reached 27 °C, the heating process with a speed rate of 1 °C/minute was done. Slow stirring was conducted until the chocolate completely melted, which was recorded as the melting point of chocolate.

2.2.4 Particle Size. Particle size of chocolate was observed using a microscope (Olympus CX23LEDRF) connected to Optilab camera (Advance Plus). A 0.5 g of chocolate was diluted in 10 ml of cooking oil and afterwards heated in an oven at 55 °C for 1 hour. After heating, the diluted chocolate is shaken vigorously until homogeneous. A drop of the chocolate solution was put on the object glass and covered with a cover glass. Subsequently, the results of the observation were captured and the particle size was measured using Image Raster 3 application. The value selected was the size of the chocolate particles [19–21].

2.2.5 Data Analysis. Statistical analysis was performed using SPSS 26.0 software. One-way analysis of variance (ANOVA) was used to test differences in physical properties of chocolate with a significance level of 5%. The test for homogeneity of variance was carried out by Levene Test. After the requirement of variance homogeneity was met, the Tukey test was performed to determine the differences among samples. Principal component analysis (PCA) was used to visualize the relationship between chocolate samples and the evaluated parameters.

3. Results and discussion

3.1. Impact of fermentation duration on the characteristics of dark chocolate

The duration of fermentation affected the physical characteristics of chocolate, namely appearance (color and glossiness), melting point, and particle size. Principal component analysis (PCA) provided an overview of the relationship between evaluated parameters and fermentation durations. From the PCA analysis, there were two components that were able to explain more than 72.12% of variance, namely PC1: 38.68% and PC2: 33.44%. It can be seen in Figure 1 that there were 4 clusters of evaluated characteristics and 3 clusters of chocolate samples.

Melting point and particle size were in the same group and inversely correlated with hue angle. Chroma and lightness were in one group and inversely correlated with glossiness (Figure 1A). It can
be seen in Figure 1B that chocolates made from unfermented / non-fermented (NF) beans tended to have higher melting point and particle size, followed by chocolates made from half-fermented (HF) and fermented (F) cocoa beans. Chocolates made from half-fermented beans tended to have a higher glossiness, while chocolate made from fermented cocoa beans showed slightly higher \( L^* \) and \( C^* \) values than chocolates made from half-fermented and unfermented cocoa beans.

![Figure 1A: PCA loading plot (A) of chocolate characteristics](image)

![Figure 1B: PCA score plot (B) of chocolates samples](image)

**Figure 1.** PCA loading plot (A) of chocolate characteristics and score plot (B) of chocolates samples

### 3.2. Color

In general, the crystal maturation affected the color of chocolates (Figure 2-4). It can be seen that Chroma (\( C^* \)) and lightness (\( L^* \)), at the beginning of maturation time, exhibited relatively low values. However once the maturation duration increased, the \( L^* \) and \( C^* \) values also increased. After about 4-7 days of maturation, chocolate made from fermented cocoa beans had higher \( L^* \) and \( C^* \) values, followed by chocolate made from unfermented and half fermented cocoa beans, consecutively. Different with \( L^* \) and \( C^* \) values, Hue (\( h \)) angle of chocolate made with fermented cocoa beans was higher than that of chocolate made from unfermented and half fermented cocoa beans, which tended to be comparable.
**Figure 2.** Lightness ($L^*$) values of chocolate made from cocoa beans fermented at different duration

**Figure 3.** Chroma ($C^*$) values of chocolates made from cocoa beans fermented at different duration

**Figure 4.** Hue ($h$) values of chocolates made from cocoa beans fermented at different duration
3.3. Glossiness
Glossiness refers to the shininess and smoothness of chocolate surface. Glossiness is an optical phenomenon that is always associated with the appearance of an object and represents the surface capacity to reflect light [22]. It can be seen in Table 2 and Figure 5 that all chocolates tended to have a comparable glossiness. This occurred because the glossiness of chocolate is mainly influenced by tempering process. In this study, the tempering process was carried out following the same treatment among samples, resulting in similar results. Chocolate that is well tempered has the desired characteristics, such as a glossy surface and optimal stability under normal storage conditions [23,24]

| Day | Fermented bean | Half fermented bean | Unfermented bean |
|-----|----------------|---------------------|------------------|
| 1   | 9.0±1.0<sup>a</sup> | 8.7±1.2<sup>a</sup> | 9.0±0.0<sup>b</sup> |
| 4   | 8.3±0.6<sup>a</sup> | 8.3±0.6<sup>a</sup> | 8.7±0.6<sup>b</sup> |
| 7   | 8.0±0.0<sup>a</sup> | 8.0±0.0<sup>a</sup> | 8.0±0.0<sup>b</sup> |
| 10  | 7.3±0.6<sup>a</sup> | 7.7±0.6<sup>a</sup> | 8.0±0.0<sup>b</sup> |
| 13  | 7.3±0.6<sup>a</sup> | 7.0±0.0<sup>b</sup> | 8.0±0.0<sup>b</sup> |

Different superscripts in the same column indicate significant differences (p<0.05) among samples

![Figure 5. Appearance of chocolate made from (a) fermented, (b) half-fermented, and (c) unfermented cocoa beans.](image)

3.4. Melting point
High quality chocolate does not melt at room temperature, but completely melts in the mouth of the consumer, giving a soft mouth feeling [17,18,25]. In general all the chocolates had melting point between 36-37 °C. As seen in Figure 6, chocolate made from fermented and half-fermented cocoa beans tended to have a comparable melting point. However, the melting point of these chocolates were slightly lower than that of chocolate made from unfermented cocoa beans. It seemed that the moisture content of the chocolates, which was influenced by the moisture content of the cocoa mass/bean (Table 1), influenced this phenomenon. It can be seen in Table 1 that the moisture content of cocoa mass made from unfermented cocoa beans was the lowest. The melting point measurement which used water, might have influence. It seemed that chocolate with high moisture was easily broken down by the water in the beaker glass during melting point measurement.
3.5. Particle size

To produce good textural and sensory qualities, particles of the chocolate should be in the correct size [17,18]. Particle sizes bigger than 30 µm create a sandy chocolate [15]. The particle size of the chocolate produced at different level of fermentation duration can be seen in Figure 7. It can be observed that particle sizes of the chocolates were not significantly different (p <0.05). This meant that 10 hours grinding duration was able to break all the cocoa nib down, regardless of the fermentation duration. From the observations (Figure 8), all types of chocolate exhibited comparable particle sizes in the range of 35-36 µm. Aside from this, it can be seen that all the chocolates did not exhibit any agglomeration, showing that the chocolates were fine enough.
Figure 8. Particle size of chocolate made from (a) fermented, (b) half-fermented (c) unfermented cocoa beans in 10x magnification

4. Conclusion
The results showed that the differences in cacao fermentation duration influenced the characteristics of dark chocolate, to some extent. Color analysis showed that chocolate made from fermented bean exhibited higher L* C* h° values than chocolates made from half-fermented and unfermented cocoa bean, consecutively. Melting point of chocolate made from unfermented cocoa bean had propensity to be higher than that of chocolate made from half-fermented and fermented bean. Glossiness and particle size of the chocolates were quite similar.

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