Roasting Time Optimization for Fermented Cocoa Beans: Effects on Chemical Composition and Sensory Profile of Cocoa Powder

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Abstract. Cocoa (*Theobroma cacao* L.) is a highly valued commodity, widely used as a raw material in the food and beverage industry. The roasting process of fermented cocoa beans is a crucial stage in determining the chemical and sensory quality of the final product, such as cocoa powder. This study aims to analyze the effect of roasting duration on the chemical characteristics (pH, moisture level, fat level, color intensity, and fineness) and sensory properties (color, flavor, and taste) of cocoa powder from fermented cocoa beans. The research employed a completely randomized design with four roasting duration treatments (30, 45, 60, and 75 minutes) at a constant temperature of 100 °C. Data were analyzed using ANOVA, and sensory evaluation was analyzed using Kruskal-Wallis and Mann-Whitney tests. The 75-minute roasting treatment yielded the best results, with pH, moisture level, fat level, color, and fineness most closely meeting the SNI quality standards for cocoa powder and achieving the highest sensory score.

1 Introduction

Cocoa (*Theobroma cacao* L.) is a strategic plantation crop with high economic value, playing a vital role in the global economy as both a raw material for the food and beverage industry and an export commodity. Based on statistical reports from the Directorate General of Plantations, Ministry of Agriculture, Indonesia's cocoa production consistently exceeded 700,000 tons per year from 2019 to 2022. The majority of this production—approximately 80%—comes from Sulawesi, the country's main cocoa-producing region.

Roasting is a critical process in cocoa bean processing that significantly influences the chemical and sensory characteristics of the final product. During roasting, temperature and time play key roles in developing flavor, color, and the physicochemical properties of cocoa beans. Roasting can decrease the pH of cocoa beans as roasting time increases, due to various chemical reactions that generate new organic acids. Thermal degradation of non-volatile components during roasting results in the formation of acidic compounds that reduce pH [1].

Roasting also causes fat loss due to evaporation; higher roasting temperatures result in greater fat loss from cocoa beans [2]. In addition, the fineness of cocoa powder improves with longer roasting time, as structural and biochemical changes in the beans occur. [3] reported that roasting leads to moisture evaporation, reducing the water level to 1–2%. This moisture reduction renders the bean structure more brittle and easier to crush, resulting in finer powder upon grinding. Previous studies have shown that roasting duration significantly affects the chemical and sensory characteristics of cocoa powder. These studies indicate that variations in roasting time can lead to noticeable differences in taste, flavor, and chemical composition [4]. [5] reported that roasting cocoa beans at 90 °C for 50 minutes produced cocoa powder with optimal characteristics and organoleptic properties. Similarly, [6] found that roasting at 140 °C for 20 minutes yielded cocoa powder with the highest consumer acceptance.

Durations outside this range tend to produce unbalanced or over-roasted profiles, underscoring the importance of optimizing roasting parameters to achieve cocoa powder with superior physicochemical and sensory characteristics. In general, the higher the roasting temperature, the shorter the time required to develop the desired chemical and sensory attributes of cocoa powder.

Nevertheless, there remains a gap in understanding the optimal roasting duration for producing cocoa powder with the best overall characteristics. Further research is therefore needed to address this gap. This study aims to provide deeper insight into the effects of roasting temperature and time on the chemical and sensory characteristics of cocoa powder and to offer recommendations for best practices in cocoa processing.

2 Materials and Methods

2.1 Tools and Materials

The tools used for this research include cocoa bean grinding tools, a Wirastar brand food dehydrator, a simple press tool, a Memmert brand oven, an Osuka brand analytical balance, a Mettler Toledo brand pH meter, a stirring rod, a cup clamp, a boiling flask, a Soxhlet extraction tool, and a Masterflex brand 800V colorimeter. The materials used for this research are fermented cocoa beans (Theobroma cacao L.) from the Makassar trinitario variety, distilled water, Petroleum ether, and Merck-brand standard pH buffers 4, 7 & 9 (pH meter standardization).

2.2 Research Procedure

This research is divided into 2 stages, (1) the process of making cocoa powder with varying roasting durations and (2) analysis of the characteristics of cocoa powder including chemical and sensory. The process of making cocoa powder begins by roasting 250 grams of dry cocoa beans at an initial oven temperature of 100 °C, with 4 roasting time variations (30, 45, 60, and 75 minutes). These cocoa nibs are ground into a paste using a simple grinder for 30 minutes. After that, a simple hydraulic press is used to separate the cocoa butter from the cocoa cake. After that, the cocoa cake is placed in a dehydrator at 55 °C for 12 hours. The cocoa cake was then ground in a blender and sieved to produce 200-mesh cocoa powder. This was followed by an analysis of the cocoa powder's chemical and sensory characteristics.

2.3 Research Parameters

2.3.1 Ph Analysis

Soursop leaf powder was sieved, then mixed with 85% methanol (1000 ml) at a 1:10 ratio. After homogenized, then macerated for 24 hours at room temperature. The obtained macerate was concentrated using a rotary evaporator at 40 ℃, 200 mbar, and 70 rpm, with modifications [7].

2.3.2 Water Level Analysis

2 g of cocoa powder was weighed into the prepared dish, and the combined weight of the sample and dish (W1) was recorded. The sample was then leveled in the dish to ensure even drying. The drying process was performed by placing the dish containing the sample in an oven set to 105 °C for 4 hours. The final weight of the sample and dish (W2) was then weighed [7].

2.3.3 Fat Level Analysis

A cocoa powder sample weighing up to 4 grams was weighed, wrapped in filter paper, and placed in an extraction lead lined with fat-free cotton (weighed as W1). The wrapped sample was then placed in a soxhlet tube. After that, petroleum ether solvent was poured into the boiling flask, filling at least 2/3 of its capacity. The extraction process was carried out for 4 hours, then the extraction lead was removed from the Soxhlet, and the remaining solvent was evaporated using an evaporator or by heating the flask over a water bath [7].

2.3.4 Colour Intensity Analysis (L, a*, b*)*

Sample preparation begins by weighing 7.5 grams of cocoa powder into a 250 ml beaker. Next, 50 ml of hot water is added to the beaker to dissolve the cocoa powder fully. After the cocoa powder and hot water are evenly mixed, the solution is directed into the Colorimeter tube. By ensuring there are no trapped air bubbles, the device is operated to read the solution's color. The measurement results will provide the L* (brightness), a* (red-green), and b* (yellow-blue) values of cocoa powder [8].

2.3.5 Finenness Analysis

10 grams of sample was taken and placed in a beaker. 1 g of detergent and 20 mL of hot distilled water. After that, 280 ml of hot distilled water (at 75 °C) was added, and the mixture was stirred vigorously for 2 minutes using a mechanical stirrer. The beaker and filter were rinsed using 1.5 L of hot distilled water (75 °C). The filter was placed into a watch glass and dried for 45 minutes at 103 °C-105 °C, then cooled in a desiccator for 20-30 minutes. After that, the filter paper, residue, and watch glass were weighed [8].

2.3.6 Sensory Analysis

The test involved 30 panelists aged 20-30 who had no history of chocolate allergy and expressed an interest in chocolate products. Sensory analysis was conducted using a hedonic test to measure panelists' preferences and acceptance of the resulting cocoa powder product [9].

2.3.7 Data Analysis

The data obtained were analyzed using Analysis of Variance (ANOVA). If there is a significant difference, further testing will be carried out, namely the DMRT (Duncan Multiple Range Test) at the 5% level. Meanwhile, for the sensory test of cocoa powder, it will be analyzed using the hedonic test with the Kruskal-Wallis test, and if there is a significant effect, it will be continued with the Mann-Whitney test to assess differences between samples.

3 Result and Discussion

3.1 The Effect of Cocoa Bean Roasting on the pH of Cocoa Powder

This means that the difference in roasting duration significantly affected the acidity of the cocoa powder. The results of the pH analysis in this study can be seen in Table 1.

Table 1. The effect of cocoa bean roasting duration on the pH of cocoa powder

Roasting duration (minutes)	Acidity (pH)
30 (P1)	5,93±0,02[a]
45 (P2)	5,85±0,02 [b]
60 (P3)	5,70±0,01[c]
75 (P4)	5,56±0,03[d]

Notes: Values followed by different notations indicate a very significant difference according to Duncan's test α = 5%.

Based on the results of the acidity (pH) analysis of cocoa powder subjected to various roasting durations, it was found that different roasting times yielded significantly different pH values. This indicates a decreasing pH (increasing acidity) with increasing roasting time. According to [10], roasting duration can affect the pH, moisture, and fat levels of cocoa powder. As shown in the table above, the pH values of all cocoa powder samples did not meet the Indonesian National Standard (SNI 3747-2013), which specifies a pH range of 1 to 5.4 for natural cocoa powder.

The mechanism of pH reduction during roasting differs from that during fermentation. During fermentation, the pH decreases due to acid production by microbial activity, whereas during roasting, the pH decline is attributed to thermochemical reactions that produce new organic acids. Roasting process, chlorogenic acid undergoes thermal degradation, producing various organic acids. Fumaric acid is formed through the degradation pathway of flavortic amino acids, particularly phenylalanine, which breaks down into cinnamic acid and subsequently into fumaric acid. [11] reported that acetic acid formation increased 3-fold during roasting, while lactic and formic acids also showed significant increases.

3.2 Effect of cocoa bean roasting on the moisture content of cocoa powder

The detailed results of the moisture content analysis in cocoa podwer with different temperature and suration are presented in Table 2.

Table 2. The effect of cocoa bean roasting duration on the water level of cocoa powder

Roasting duration (minutes)	Water Level (%)
30 (P1)	4,60±0,17[a]
45 (P2)	4,41±0,03[ab]
60 (P3)	4,21±0,09[bc]
75 (P4)	4,05±0,09[c]

Notwes : Values followed by different notations indicate a very significant difference

Moisture contentl is one of the most important chemical quality parameters in the food industry, as it is closely related to product quality and shelf stability. Longer roasting times led to lower moisture levels in cocoa beans. This reduction is attributed to the evaporation of free water from the surface of the nib cell walls, which predominantly occurs during roasting. Overall, the moisture levels obtained in all treatments met the Indonesian National Standard (SNI 3747-2013) for cocoa powder, which requires a maximum moisture level of 5%.

The significant effect of roasting duration on moisture level reduction is due to water evaporation during heating. Roasting induces physical and chemical changes, including progressively more intense water evaporation over time. At 30 minutes of roasting, water evaporation is still in the early stage and not yet optimal, as the heat has not been applied long enough to evaporate water within the deeper structures of the nibs. At this stage, moisture loss occurs primarily on the surface, while the water level within the inner cells remains relatively high. The reduction in moisture level has several beneficial effects on cocoa powder, including improved shelf stability. According to SNI 3747-2013, the maximum permissible moisture level for cocoa powder is 5%. If this threshold is exceeded, the risk of microbial growth, such as mold, increases, potentially leading to product spoilage and quality degradation during storage. Low moisture level results in lower water activity, thereby inhibiting microbial growth and extending shelf life. Studies have shown that cocoa powder with low moisture level, when stored in moisture- and gas-impermeable packaging, can maintain its quality for several hundred days. Conversely, if moisture levels increase due to water vapor absorption during storage, cocoa powder tends to clump, discolor, and experience a decline in organoleptic quality [12].

3.3 Ash Effect of cocoa bean roasting on the fat level of cocoa powder

The detailed results of fat level analysis cacao powder with difference temperature and time presented in Table 3.

Table 3. The effect of cocoa bean roasting duration on the fat level of cocoa powder

Roasting duration (minutes)	Water Level (%)
30 (P1)	45,09±0,72[a]
45 (P2)	44,02±0,29[b]
60 (P3)	42,57±0,23[c]
75 (P4)	41,95±0,10[c]

Notes: Values followed by different notations indicate a very significant difference according to Duncan's Test α = 5%.

Longer roasting times led to a reduction in the fat level of cocoa beans. Based on the fat levels obtained in this study (41.95%–45.09%), these levels are well above the Indonesian National Standard (SNI 3747), which specifies a minimum fat level of 10% for cocoa powder. Thus, despite the reduction in fat level with longer roasting durations, all samples still met the SNI minimum requirement. When cocoa beans are heated during roasting, thermal energy destabilizes weak bonds in phospholipids—such as hydrogen bonds and hydrophobic interactions—causing them to break. This release allows fats previously trapped within the cell structure to become more mobile and easier to extract during cocoa powder pressing. As explained by [13], heating can break the double bonds of fatty acids in glycerides, leading to a reduction in fatty acid levels as roasting continues for longer durations.

[14] reported that approximately 5–15% of total cocoa fat exists in a bound form with proteins through hydrophobic interactions. During roasting, the breaking of these bonds makes the fat more mobile, enabling its removal through physical processes such as pressing. Prolonged

roasting increases lipoprotein denaturation, thereby releasing more fat that becomes easier to extract during pressing. Consequently, cocoa powder samples roasted for longer durations contain lower fat levels after pressing.

This is also influenced by the pressure applied during the cocoa cake pressing stage, which helps determine the residual fat level. During pressing, both chemical and physical changes occur in the cocoa solids. Greater fat reduction can enhance the release of chocolate flavor compounds, but may also result in a coarser mouthfeel [15]. Insufficient pressing pressure may reduce the efficiency of fat removal from cocoa beans, leaving more fat trapped in the resulting cocoa powder. [16] highlighted that optimal pressing pressure is essential for efficient cocoa butter extraction, and inadequate pressure can lead to higher fat level in the final product.

3.4 Effect of cocoa bean roasting on the color intensity of L*a*b* cocoa powder

This indicates that variations in roasting duration significantly influence the L*a*b* color intensity of cocoa powder. The detailed results of the moisture level analysis in this study are presented in Table 4.

Table 4. The effect of cocoa bean roasting duration on the color intensity of cocoa powder

Roasting Duration (minutes)	Color Intensity (%)		
	L*	a*	b*
30 (P1)	45,60±0,25^{a}	12,18±0,34^{a}	17,29±0,15^{a}
45 (P2)	43,29±0,34^{b}	13,26±0,31^{b}	16,39±0,30^{b}
60 (P3)	41,31±0,19^{c}	14,51±0,54^{c}	15,08±0,29^{c}
75 (P4)	35,26±0,47^{d}	16,94±0,11^{d}	12,42±0,35^{d}

Values followed by different notations indicate a very significant difference according to Duncan's Test α = 5%.

The L* value represents lightness, ranging from black to white, with a scale from 0 to 100. A higher L* value indicates a lighter product color. Roasting duration (30, 45, 60, and 75 minutes) significantly affected L* values, with a decrease from 45.60 at 30 minutes to 35.26 at 75 minutes. This phenomenon occurs because prolonged roasting intensifies the Maillard reaction and caramelization, both of which are non-enzymatic browning processes [17]. According to [18], the Maillard reaction between amino groups from proteins and carbonyl groups from carbohydrates during heating produces brown pigments that influence cocoa bean color. At shorter roasting times (30 minutes), the Maillard reaction has just begun and has not yet produced much melanoidin, whereas at longer roasting times (75 minutes), melanoidin accumulation reaches its peak.

Roasting duration significantly influenced the a* value. The increase in a* value with longer roasting times is attributed to intensified Maillard and caramelization reactions at higher temperatures [19]. The Maillard reaction between reducing sugars and amino acids produces melanoidins, which contribute to reddish-brown coloration. This is related to the formation of dark red and brown pigments and the degradation of polyphenols—particularly anthocyanins and flavonoids—during roasting, which impart the characteristic reddish-brown color to cocoa powder. Longer roasting increases melanoidin formation, thus enhancing the red color intensity (a* value). Based on ICCO standards (2023), the optimal a* value for premium cocoa ranges between 13 and 16. Samples roasted for 45–75 minutes (a* values of 13.26–16.94) met this criterion, while the 30-minute sample (a* value of 12.18) did not, indicating under-roasting. In Indonesia, SNI 3747:2013 does not specify a* values but requires fully fermented cocoa beans to have a uniform reddish-brown to dark brown color.

The b* value indicates the chromatic component from blue to yellow, with a range of 0 to 70 for yellow and −70 to 0 for blue. A higher b* value corresponds to greater yellowness [20]. In this study, b* values ranged from 12.42 to 17.29. The data revealed a decrease in b* value with increased roasting time: 17.29 (30 min), 16.39 (45 min), 15.08 (60 min), and 12.42 (75 min). Roasting duration significantly influenced the b* value of cocoa powder. The reduction in b* indicates a decrease in yellowness. This change is due to anthocyanin degradation and the formation of yellow-brown compounds via the Maillard reaction. The decrease from 17.29 at 30 minutes to 12.42 at 75 minutes indicates the breakdown of heat-sensitive flavonoids (e.g., epicatechin) and carotenoids, which degrade into brown pigments during roasting [21].

3.5 Effect of Roasting Cocoa Beans on the Fineness of Cocoa Powder

The detailed results of the fineness analysis for cocoa powder at varying temperatures and times are presented in Table 5.

Table 5. The effect of cocoa bean roasting duration on the fineness of cocoa powder

Roasting duration (minutes)	Fineness (%)
30 (P1)	90,03±0,67[a]
45 (P2)	91,48±0,76[b]
60 (P3)	92,95±0,48[c]
75 (P4)	94,19±0,20[d]

Explanation: Values followed by different notations indicate a very significant difference according to Duncan's Test $\alpha = 5\%$.

Based on these results, the cocoa powder produced in this study did not meet the requirements of SNI 3747, which stipulates a minimum fineness of 99.5%. The findings show that fineness increased from 90.03% at 30 minutes to 94.19% at 75 minutes, indicating that roasting duration affects cocoa powder fineness. Longer roasting times make cocoa beans easier to grind, resulting in finer powder. Roasting not only reduces moisture levels and develops flavor but also loosens the seed coat, facilitating separation from the nibs, and increases the brittleness of the nibs, which makes grinding and refining easier [22]. Although fineness improved with longer roasting durations, the values remained far below the required standard.

A study conducted by [23] reported an average cocoa powder fineness of 99.67% at a roasting temperature of 100 °C with treatment times ranging from 30 to 120 minutes. One of the main causes of the low fineness in this study was suboptimal grinding. Cocoa powder fineness is highly dependent on the grinding process after roasting. If the cocoa beans are not ground at sufficient speed or pressure, the resulting particle size will remain large, resulting in low fineness. This is consistent with the findings of [24] , who stated that inadequate grinding—whether in terms of pressure or duration—results in coarser powder particles that do not meet desired fineness standards.

Another factor affecting fineness is the particle size of the cocoa bean cotyledons. Larger particle sizes in the beans will yield coarser powder, even with extended roasting durations. If the cocoa beans used have non-uniform particle sizes, grinding will produce cocoa powder with variable fineness. [25] emphasized that the particle size of cocoa bean cotyledons plays a crucial role in determining the fineness level of the resulting cocoa powder.

3.6 Effect of Cocoa Bean Roasting on the Hedonic Test of Cocoa Powder

This study assessed three sensory attributes—color, taste, and flavor—of cocoa powder. The panelists involved were untrained consumers. Each panelist was asked to provide an evaluation on a numerical scale from 1 to 5, where 1 = dislike very much, 2 = dislike, 3 = like, 4 = like very much, and 5 = like extremely. The results were calculated by summing each attribute's

score and dividing by the total number of panelists. The results of the sensory evaluation are shown in Table 6.

Table 6. The effect of cocoa bean roasting duration on the fineness of cocoa powder

Roasting Duration (minutes)	Color	Flavor	Taste
30 (P1)	$2,10 \pm 1,06^{a}$	$2,53 \pm 1,13^{a}$	$1,97 \pm 0,92^{a}$
45 (P2)	$2,47 \pm 0,57^{a}$	$2,73 \pm 0,94^{a}$	$2,33 \pm 0,71^{a}$
60 (P3)	$3,17 \pm 0,79^{b}$	$2,87 \pm 0,77^{a}$	$2.97 \pm 0,49^{b}$
75 (P4)	$3,57 \pm 1,13^{b}$	$3,73 \pm 1,11^{b}$	$3,53 \pm 0,86^{c}$

Notes: Values followed by different notations indicate a very significant difference according to Duncan's Test $\alpha = 5\%$.

Based on Table 6, the average color preference increased significantly with longer roasting durations. This is because extended roasting times can enhance the development of cocoa powder's characteristic brown color. The distinctive brown color of cocoa products is primarily formed through non-enzymatic browning, particularly caramelization. This phenomenon occurs when polyhydroxy carbonyl compounds (reducing sugars) are heated, producing notable changes in flavor, color, and aroma. Prolonged thermal processing can lead to the formation of compounds with bitter notes, darker coloration that can blacken, and burnt sensations.

Flavor is one of the primary attributes influencing consumers food choices. [26] noted that in many cases, the enjoyment of food is strongly influenced by its flavor. The results showed that flavor preference increased with longer roasting durations. This may be attributed to the fact that both roasting temperature and duration greatly influence the resulting flavor of cocoa powder [27]. [28] explained that cocoa bean roasting triggers Maillard and Strecker degradation reactions, producing various volatile compounds such as pyrazines, aldehydes, ketones, and furans that contribute to the characteristic chocolate flavor. Longer roasting allows for optimal formation of these flavortic compounds, resulting in a more preferred flavor profile. This finding supports [29], who reported that chocolate flavor intensity increases with roasting time until reaching an optimal point. In the present study, the 75-minute roast (P4) yielded the highest flavor preference score.

Taste is another critical factor influencing consumer acceptance of food products. Based on the hedonic test results, roasting duration significantly affected taste preference scores for cocoa powder, with higher scores recorded for longer roasting times. This can be explained by the biochemical changes occurring during roasting. [30] reported that roasting initiates Maillard reactions, producing complex cocoa flavor precursors. Longer roasting allows sufficient time for the formation of desirable flavor compounds while reducing excessive bitterness and astringency, which are less preferred. Chemical reactions during roasting, such as the Maillard reaction and caramelization, influence not only color and flavor but also yield a more complex and preferred taste profile. Extended roasting enhances the development of compounds responsible for the characteristic chocolate flavor that consumers generally favor.

4 Conclusion

Based on this study's results, roasting duration significantly affected the chemical and sensory characteristics of cocoa powder. Increasing the roasting duration decreased cocoa powder pH, moisture, and fat levels, and altered color intensity, while improving powder fineness. A 75-minute roasting treatment was identified as the optimal condition, as it produced pH, moisture level, fat level, fineness, and color intensity values that closely met the Indonesian National Standard (SNI) for cocoa powder quality. Moreover, this treatment achieved the highest sensory scores from the panelists.

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