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Physical and flavor qualities of cocoa beans affected by different box fermenter capacity, fermentation length, and microbial cultures

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Abstract. Indonesia is one of the world's cocoa producers, yet the quality of its cocoa production remains relatively low. To enhance this quality, cocoa bean fermentation is crucial. A study was conducted to assess the impact of different fermentation conditions on cocoa bean quality. Two fermentation boxes were used: a 10-kilogram capacity (K1) and a 20-kilogram capacity (K2) fermentor. The fermentation process involved different treatments, including spontaneous fermentation (Y0), and inoculated with different bacteria: *Lactobacillus plantarum* (Y1), *Saccharomyces cerevisiae* (Y2), and combination (Y3). The fermentation was carried out over three different periods: 3 (W1), 4 (W2), and five days (W3). Several parameters were observed throughout the process, including the final composition of the fermented beans, precise temperature, pH levels, and the physical quality of the cocoa beans.Additionally, flavour attributes were analysed using Quantitative Descriptive Analysis (QDA). The flavour profile evaluated included cacao intensity, degree of roasting, bitterness, astringency, total acidity, fruity notes, acetic acid, lactic acid, and mineral and butyric characteristics. The result showed that fermentation using a combination of microorganisms showed the lowest percentage of cocoa per 100 g and slaty beans. The flavor quality showed various results according to the fermentor capacity and the microorganism used as a starter.

1 Introduction

The chocolate industry and processed cocoa products rely heavily on high-quality cocoa beans that have undergone good fermentation. High-quality, well-fermented cocoa beans are essential to producing high-quality chocolate [1]. Cocoa beans that have undergone proper fermentation form an essential basis for producing high-quality

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Chocolate products. The quality of chocolate produced depends on the cocoa beans' quality. Good cocoa beans produce chocolate with consistent flavor characteristics and meet industry quality standards [2].

The fermentation process of cocoa beans is a crucial stage in cocoa bean processing, significantly influencing the chocolate product's quality and final characteristics [2], [3]. One effect that can occur during fermentation is a decrease in the polyphenol content of the cocoa beans [4]. Polyphenols are antioxidant compounds that exist naturally in cocoa beans and play an essential role in providing taste, aroma, and health benefits to chocolate products. During fermentation, chemical reactions occur, which can cause the degradation of some of these polyphenolic compounds [5].

Overall, properly fermented cocoa beans are an essential component for making high-quality chocolate. The chocolate industry needs high-quality cocoa beans to ensure that the final product meets quality standards and consumer expectations. Therefore, careful supervision and management of cocoa bean fermentation are essential in this industry.
This study aims to analyze fermentation's impact on cocoa nibs, liquor, and powder quality affected by the capacity of the fermentation box, bacterial composition, and fermentation duration.

2 Methodology

2.1 Cocoa Bean Fermentation

The fermentation of cocoa beans consisted of three steps: pre-fermentation, fermentation, and drying. In pre-fermentation, the ripe cacao pods were sorted and stored in a closed container for 24 hours after being harvested from the tree. After 24 h of storage, the pods were cracked open, and the wet white beans were selected for subsequent process.

In the fermentation process, the selected white beans were placed in a 20-kg- (K1) and 40-kg-fermentor box (K2) until complete; then, the box was covered with clean banana leaves. The fermentation was conducted for three days (W1), four days (W2), and five days (W3), and every 48 hours, the beans were turned over in a new fermentor box. Sample matrices are displayed in Table 1.

The drying process was carried out using a solar dryer with a relative humidity of 45%. The fermented beans were spread out above the bamboo or stainless steel tray and dried for three days or until the moisture content was 7%. The dried beans were sampled and subjected to physical and polyphenol assays, flavor attributes, and organoleptic testing. The beans were packed in a plastic bag and burlap sack for the secondary packaging.

Table 1. Sample matrices

Duration of fermentation / Box fermentor capacity	3 days (W1)	4 days (W2)	5 days (W3)
20-kg (K1)	K1W1	K1W2	K1W3
40-kg (K2)	K2W2	K2W2	K3W3

2.2 Evaluation of Physical Properties

The physical properties of fermented beans were analyzed, including the number of seeds per 100 grams and the slaty bean content. Both analyses were carried out using the Indonesian National Standard (SNI 2323:2008) methods.

2.3 Flavor Attributes

The flavor attributes of dried fermented beans, alkalized nibs, and powder were assayed using the International Standard for the Assessment of Cocoa Quality and Flavor (ISCQF) by seven trained panelists. Sensory evaluation for five core flavor attributes was performed for fermented cacao beans, including roast degree, cacao, total acidity, bitterness, and astringency, as well as four total acidity flavors: fruit, acetic, lactic, mineral, and butyric, so in total nine flavor attributes were evaluated.

3 Result and Discussion

3.1 Physical Properties of Fermented Cocoa Beans

The fermented bean was analyzed for the bean count value per 100 g affected by microbial inoculation, as shown in Figure 1. This study found the highest number of beans per 100 grams in beans that were fermented spontaneously (without any particular microbial inoculation). Microbial inoculation of cacao beans during fermentation can significantly affect their physical properties. Inoculation with specific yeast isolates can increase the temperature of the bean mass compared to control [6] and result in the optimal pH for flavor precursor concentration during fermentation [7]. [8] stated that the number of beans/100 g increased with increasing fermentation and drying periods. The higher number of beans per 100 g of cocoa observed in beans fermented with spontaneous fermentation may be attributed to the high loss of nutrient components due to the numerous microorganisms involved in the fermentation process. The standard of bean grading may vary according to country or organization. For example, the Federation of Cocoa Commerce (FCC) stated that the standard number of imported beans is 100 per 100 g. The standard based on the Cocoa Merchants' Association of America or CMAA is 1000 bean count, and 105 per 100 g The Conseil Café Cacao Côte d'Ivoire.

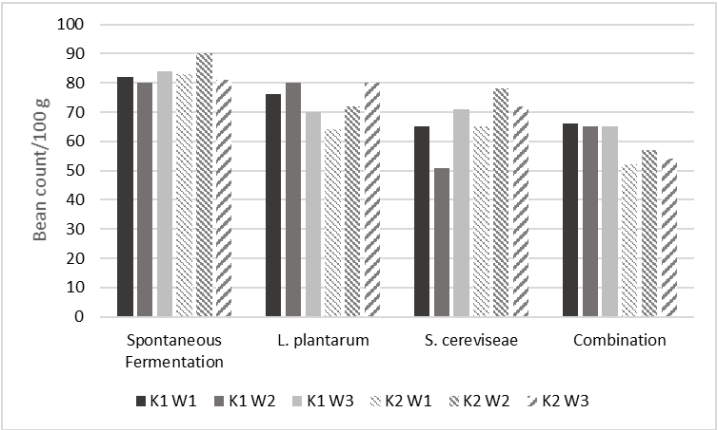

Fig. 1. Fermented dried cocoa bean count per 100 grams.

3.2 Percentage of Slaty Beans

Slaty cocoa beans refer to cocoa beans that have been affected by problems such as over-fermentation, sprouting, or being affected by insects. The result showed that the highest percentage of slaty beans was in spontaneous fermentation. For all samples, the percentage of slaty beans ranges between 20 – 17%. The fermentation process, which was inoculated with *L. plantarum* and *S. cerevisiae*, showed similar results of slaty beans ranging between 9-3%, for combination inoculation showed the lowest result of 6-10 % slaty beans. Biochemical changes occurred during the fermentation, causing the formation of precursor molecules that reduce defective or slaty beans and allow them to turn brown instead of purple.

Fermentation of cocoa beans significantly decreases the occurrence of slaty beans, which indicates poor quality. Research indicates that applying *Lactobacillus fermentum* during fermentation led to a notable reduction in slaty and purple beans, enhancing the overall sensory quality of the cocoa [9]. Additionally, a study found that after 48 hours of fermentation, there was a significant decrease in slaty seeds, alongside an increase in partially fermented beans and bioactive compounds [10].

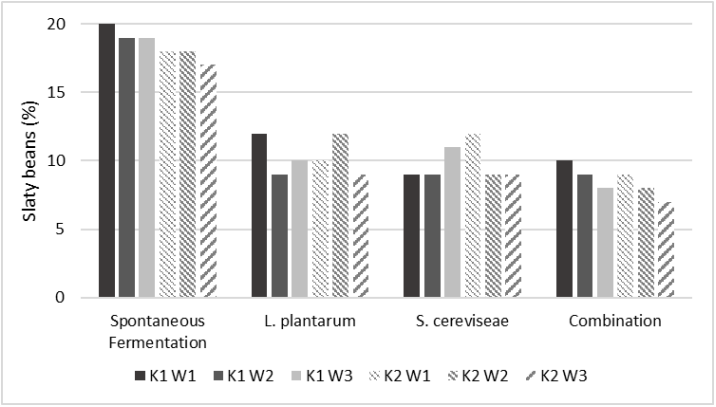

Fig. 2. Percentage of slaty beans in dried fermented cacao beans.

3.3 Flavor Attributes

After harvest, cocoa beans undergo complex processing that changes their initial chemical and physical characteristics to enhance the taste and achieve the desired chocolate flavors [11]. The flavor attribute of cocoa is formed from the fermentation and roasting process of cocoa beans. During fermentation, flavor precursors are formed, which are compounds that will later form flavors after roasting. Precursors form after the third day of fermentation, when cocoa beans are soaked with acid and cocoa cells begin to decompose. During roasting, precursors are converted into aromatic compounds by the Maillard reaction and Strecker degradations, forming about 600 types of volatile compounds [12]. Some compounds formed during roasting include phenylacetaldehyde, isovaleraldehyde, isopentane, and pyrazine, which contribute to cocoa flavor. Cocoa flavor can also be influenced by the variety of cocoa beans, with different types having different flavor attributes such as fresh fruit, yellow fruit, floral, woody, spicy, nutty, sweet, caramel, Panella, brown sugar, and roasted.

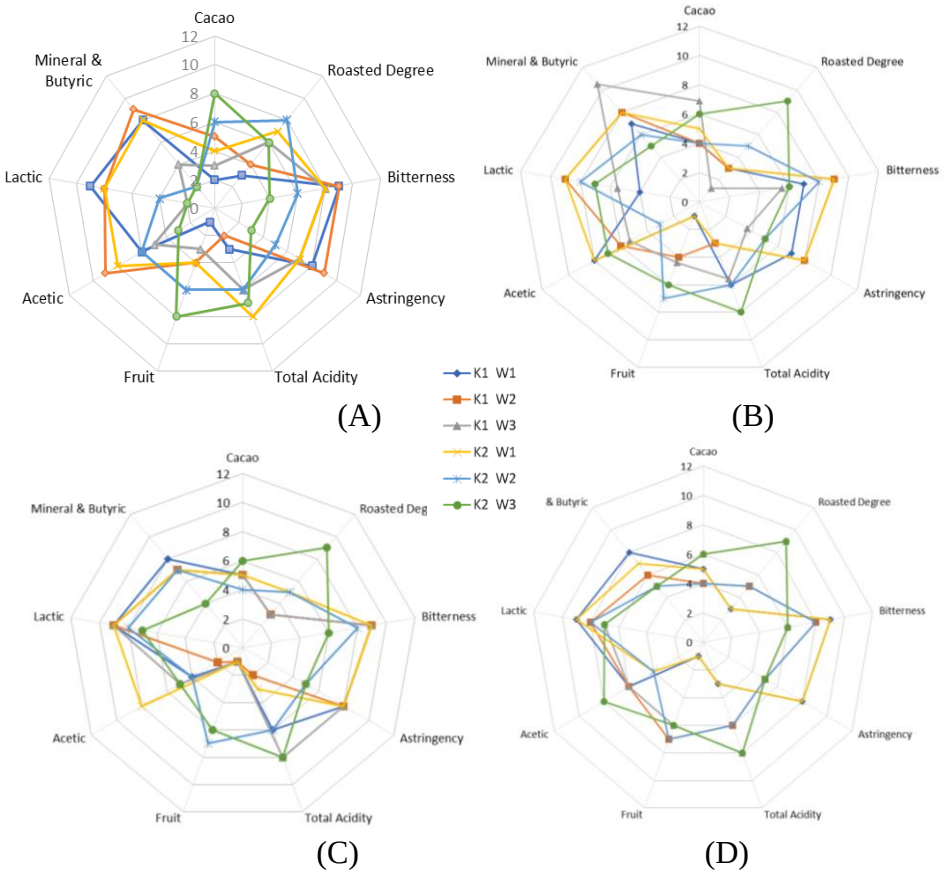

Fig. 3. Flavour attributes of cacao beans fermented spontaneously (A), with the inoculation of *L. plantarum* (B), *S. cerevisiae* (C), and combination of both microorganisms (D)

Figure 3 shows the flavour attributes of cocoa bean fermentation with treatments of fermented spontaneously (A), inoculation of *L. plantarum* (B), *S. cerevisiae* (C), and a combination of both microorganisms (D) in 10 kg or 20 kg fermentation boxes for 3, 4, or 5 days. The figure indicates that the 20 kg box with five days of fermentation has the highest cacao flavour except for *L. plantarum*, the highest roast degree, and the highest total acidity except for the control (A). Cocoa refers to the primary flavour derived from cocoa beans. It can include a variety of flavours, including nutty, fruity, floral, earthy, and sometimes spicy or aromatic. The aldehydes and ketones compounds play a role in the emergence of cocoa flavour, especially in the compounds 4-methyl-2-phenyl-2-pentenal and 5-methyl-2-phenyl-2-hexenal, which show a profound bitter cocoa note [11].

Adding *S. cerevisiae* will bring out the highest bitterness and lactic acidity compared to other inoculations. Bitterness is an inherent characteristic of cocoa due to compounds such as theobromine and flavonoids. When appropriately balanced, it enhances the depth and complexity of the chocolate flavour. Nevertheless, an excessive amount of bitterness can overpower the taste receptors. While roasting, theobromine and caffeine combine with diketopiperazines in a 1:2 mole ratio, generating adducts that contribute to the distinct bitterness found in roasted beans [11]. Lactic acid is a milder acidity often found in dairy products due to fermentation, such as yogurt or certain cheeses. It contributes a smooth, slightly tangy, and creamy taste.

The 20 kg box with fermentation durations of 4 and 5 days shows astringency scores that are not excessively high compared to other treatments. Astringency is the drying or puckering sensation in the mouth caused by tannins in cacao. Astringency in chocolate could be desirable, but excess may lead to an unpleasant, dry, or chalky mouthfeel. In fermentation, biochemical reactions produce cocoa flavour precursors such as reducing sugars and nitrogenous compounds. In the anaerobic phase, sucrose undergoes partial hydrolysis to reduce sugars, proteins break down through proteolysis into peptides and amino acids, and polyphenols undergo hydrolysis and oxidation. The aerobic phase involves oxidative and condensation reactions, such as the oxidation of protein-polyphenol complexes and carbonyl-amino condensation, which work to decrease astringency [12].

The highest fruit acidity score is observed in the control treatment (A) with a 20 kg fermentation box for five days. The addition of *L. plantarum* (B), *S. cerevisiae* (C), and a combination of both (D) in the 20 kg box for 4 days obtained high fruit flavors compared to other treatments. Fruit acidity refers to the perceived acidity in food or drinks resembling the tartness of various fruits. This acidity is often bright and refreshing and can present as citrusy (like lemon or orange) or resemble the acidity of berries or other tangy fruits. During fermentation, alcohol occurs due to microbial activity conferring a fruity, green, and floral flavour [11].

Adding *L. plantarum* (B) will cause the strongest acetic, mineral, and butyric flavour compared to adding other inoculations. Acetic acid is the primary component of vinegar and is characterized by a sharp, pungent, and sour taste resembling the sharpness of vinegar or the sourness of fermented products. The organic acid levels rise throughout the fermentation process due to sugar metabolism. Acetic acid, known for its sour and vinegar-like scent, is the most prominent odor-producing compound in fermented and unroasted beans [11]. Mineral acidity is less about a specific taste and more about a sensation. It is described as a clean, sharp, or sometimes metallic taste associated with specific minerals. Meanwhile, butyric acid is found in some dairy products and sometimes has a slightly rancid or sour taste. It contributes to the flavor profile of certain cheeses in small amounts, but in higher concentrations, it can lead to an off-putting, vomit-like aroma or taste.

4 Conclusion

The research and results show that the highest number of cocoa beans is 100 grams of spontaneous fermentation without adding specific microbial inoculations. In the test results, the % of slaty bean samples containing the number of slaty beans contained in the spontaneous fermentation is 20-17% of slaty cocoa beans. The flavor attribute results show that the box 20 kg with five days of fermentation tastes high, except in the sample added with *L. plantarum*. Adding *S. cerevisiae* will produce the most bitterness and lactic acidity compared to other inoculations. 20 kg boxes with fermentation durations of 4 and 5 days showed not very high astringency scores compared to other treatments. Control A, with a box capacity of 20 kg with a long fermentation of 4 days, produces good fruit flavor compared with other treatments.

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