BIOLOGY, MEDICINE, & NATURAL PRODUCT CHEMISTRY ISSN 2089-6514 (paper)
Volume 15, Number 2, October 2026 | Pages: 2003-2010 | DOI: 10.14421/biomedich.2026.152.2003-2010 ISSN 2540-9328 (online)

Effect of Fermentation Time and Sucrose Concentration on the Quality Characteristics of Refermented Dried Cocoa Beans (MCC02)

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Manuscript received: 22 April 2026. Revision accepted: 28 September 2026, Published: 05 November 2026.

Abstract

The quality of Indonesian cocoa beans in the international market remains relatively low due to suboptimal post-harvest handling. The fermentation process, typically carried out by farmers for 4–5 days in accordance with SNI standards, is often uncontrolled due to limited fermentation facilities, resulting in a high moisture content and an underdeveloped flavor. This study aimed to (1) analyze the quality of re-fermented cocoa beans based on SNI Cocoa Beans No. 2323-2008 under treatments involving different sucrose concentrations and fermentation times, and (2) analyze the fermentation index values of re-fermented cocoa beans under the same treatments. The study employed a factorial design with two factors: sucrose concentration (0%, 2.5%, 5%, 7.5%, and 10%) and fermentation duration (1, 2, and 3 days). Re-fermentation was carried out on farmers' dried cocoa beans using fermentation bags with added sucrose as a process catalyst. The parameters observed included compliance with SNI Cocoa Beans No. 2323-2008 and fermentation index values measured using a spectrophotometer. The results showed that fermentation time had a major effect on the physical properties of cocoa beans (moisture content and weight), whilst sucrose concentration had a greater influence on biochemical aspects (pH and fermentation index). The optimal combination was achieved with a 2-day fermentation period and 2.5% sucrose (A2 × B1), yielding bean quality closest to ideal conditions. Re-fermentation was found to improve cocoa bean quality compared to unrefmented beans, suggesting its potential as a quality-enhancement solution at the farmer level.

Keywords: Cocoa; fermentation index; sucrosa; Refermentation.

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is one of Indonesia's major plantation commodities, playing a vital role in the national economy and farmers' welfare. However, the quality of Indonesian cocoa beans in the international market remains relatively low, thereby affecting farmers' competitiveness and selling prices. One of the main causes of the low quality of cocoa beans is suboptimal post-harvest handling, particularly during the fermentation stage — a process that is crucial in determining the formation of flavor precursors, color, and the physical characteristics of cocoa beans (Sari et al. 2025).

The cocoa bean fermentation process is a series of microbiological and biochemical reactions involving yeast, lactic acid bacteria, and acetic acid bacteria, as well as the beans' endogenous enzymes, to form aromatic compounds, reduce bitterness/astringency, and improve bean color (Analianasari et al, 2023). Recent research indicates that microbes and fermentation conditions—such as duration, temperature, and aeration—play a crucial role in determining the final quality of the beans (Calvo et al. 2021). On a small-scale basis, many farmers in Indonesia still sell 'raw' beans (unfermented or under-fermented) due to limited fermentation facilities, the lengthy process, and a lack of technical knowledge (Febrianto & Zhi, 2020).

The national standard, SNI 2323:2008, stipulates a conventional fermentation duration of approximately 4–5 days using suitable fermentation containers (BSN, 2008). However, field practices often fall short of these standards, resulting in cocoa beans with high moisture content, inconsistent color, and a characteristic flavor that has not developed properly. Recent research indicates that under optimal conditions, fermentation duration can be shortened through microbial control interventions and fermentation conditions (Sabahannur & Syam, 2025).

In improving the quality of cocoa beans from smallholder farmers, the re-fermentation approach (re-fermenting dried beans) offers an attractive option for enhancing bean quality without requiring large fermentation vessels or lengthy fermentation times.

Furthermore, the addition of sugar substrates such as sucrose has been reported as a strategy to provide an additional carbon source for fermentative microorganisms, which can enhance microbial activity and accelerate the formation of aroma compounds in a shorter timeframe (Andrade Silva et al. 2024)

Based on these findings, this study was designed to evaluate the effects of fermentation duration (1–3 days) and sucrose concentration on the quality characteristics of re-fermented dry cocoa beans of the MCC02 variety. The objectives of the study are: (1) to analyze the quality of re-fermented cocoa beans based on SNI 2323-2008; and (2) to analyze the Fermentation Index (FI) as an indicator of internal biochemical changes during the re-fermentation process. It is hoped that the results of this study will provide a practical and affordable method for smallholder farmers to improve the quality of cocoa beans and export competitiveness.

MATERIALS AND METHODS

Study area

The research was conducted from June to August 2025 at the Agro-Industrial Product Development Laboratory of the Lampung State Polytechnic, Indonesia. A total of 70 kg of cocoa beans was obtained from Bulok Tanggamus Regency, Lampung Province. The equipment used in this study included a pH meter, oven, analytical balance, spatula, beaker, desiccator, filter paper, measuring pipette, measuring cylinder, and UV-Vis spectrophotometer.

This study was designed using a randomized block design (RBD) with a two-factor factorial pattern. The first factor (A) was fermentation time with three levels (1 day, 2 days, and 3 days). The second factor (B) was granulated sugar concentration with five levels (0%, 2.5%, 5%, 7.5%, and 10%). The control consisted of two treatments: a treatment without added sugar (0%) and a treatment using farmers' cocoa beans fermented in accordance with SNI, with the aim of comparing the resulting fermentation index levels.

Fermentation of Cocoa Beans

The cocoa beans, sourced from cocoa farmers, had been dried for 3 days, with a moisture content of>14%. The beans were sorted to remove immature, flattened, and moldy beans. Next, 2 kg of cocoa beans were weighed, placed in a 10-liter container, and 3 liters of water were added to submerge the beans. Sucrose was added to the water at varying concentrations and for different fermentation durations.

Research Method

Measurement of Moisture Content (%) in Fermented Cocoa Beans

Moisture content is the percentage of water mass contained in the material (cocoa beans) compared to the total mass of the material. Moisture content is determined using the gravimetric method. The equation for calculating moisture content is as follows:

$$\textbf{Moisture Content}\ (\%) = \frac{Wb - Wk}{Wb} x\ 100\%$$

Notes:
Wb: Weight of cocoa beans before drying (g)
Wk: Weight of cocoa beans after drying in an oven at 105°C for 16–24 hours (g)

pH Measurement of Fermented Cocoa Beans

pH measurement of fermented beans is carried out according to (AOAC, 2005). A 5 g sample of crushed cocoa beans from each day of fermentation is weighed, placed in an Erlenmeyer flask, and 45 ml of hot distilled water at 90°C is added, stirred using a magnetic stirrer. The suspension is filtered to obtain the filtrate (*aliquot*), then cooled to 27 ± 2 °C, and the pH is determined using a pH meter.

Analysis of the Fermentation Index of Re-fermented Cocoa Beans

The fermentation index was determined according to Gourieva & Tserevitinov (1979) by grinding a sample of dried cocoa nibs, then weighing 0.5 g of the resulting cocoa powder and extracting it with 50 ml of a methanol-hydrochloric acid mixture (97:3, v/v). The extract was cooled at 8 °C for 16–19 hours, then filtered through filter paper. The absorbance of the clear extract was measured at 460 nm and 530 nm using a UV-Vis spectrophotometer. The fermentation index was calculated as the ratio of absorbance at 460 nm to that at 530 nm. Fermentation was considered successful if the fermentation index reached 1 or higher.

Number of dried fermented cocoa beans per 100 g

Quality testing of the cocoa beans was carried out by weighing them; the data showed that there were 86 cocoa beans in 100 grams of dried cocoa beans.



Figure 1. Raw materials: MCC 02 cocoa pods and cocoa beans with a moisture content >20% (sun-dried for 3 days by farmers).

RESULTS AND DISCUSSION

The dry cocoa bean re-fermentation process is one of the post-harvest technological strategies developed to improve the quality of under-fermented or unfermented cocoa beans. The main problem with Indonesian cocoa is the low level of fermentation at the farmer level, which results in the majority of traded cocoa beans being of low quality. Tulnafsi et al., (2025) stated that yeast concentration and stirring time significantly influence almost all cocoa bean quality parameters, including moisture content, fermentation index, bean pH, and fat content. This study examined two main factors: fermentation time (AP, A1, A2, A3, KA) and sucrose concentration as an additional substrate (BP, B1, B2, B3, B4, KB).

The results of the analysis of variance (Table 1) indicate that fermentation time has a significant to highly significant effect on all observed parameters, including moisture content, pH, fermentation index, and the weight of 100 re-fermented cocoa beans. This confirms that fermentation duration is the most consistent and dominant factor in determining the quality of the resulting cocoa beans. Sucrose concentration exerted a more selective influence, being highly significant only for the fermentation index and significant for pH, but not significantly affecting moisture content or the weight of 100 beans. The interaction between fermentation time and sucrose was highly significant for pH and significant for the fermentation index, indicating that these two factors do not act independently on the biochemical parameters of the beans.

Table 1. Analysis of variance for the effects of sucrose and fermentation time on moisture content, pH, fermentation index, and weight of 100 re-fermented cocoa beans.

Treatment	Moisture content (%)	pH	Fermentation index	Weight of 100 seeds (g)
Fermentation time	*	**	*	**
Sucrose	tn	*	**	tn
Fermentation time*Sucrose	tn	**	*	tn

Notes: *: noticeable; **: very real; tn: not evident

Moisture Content (%) of Fermented Cocoa Beans

Effect of Fermentation Time on Moisture Content

The results of the analysis of variance (Table 1) show that fermentation time has a significant effect (*) on the moisture content of re-fermented cocoa beans, whilst sucrose concentration and its interaction have no significant effect (n.s.). The results of the 5% BNJ test are presented in Table 2.

Table 2. Mean Moisture Content (%) of Re-fermented Cocoa Beans Based on Fermentation and Sucrose Treatments.

Fermentation Treatment	Moisture Content (%)	Sucrose Treatment	Moisture Content (%)
AP (5-day fermentation by farmers)	**10.84a**	BP (farmer-fermented from fresh cocoa pods)	**10.84**
A1 (1-day fermentation)	**7.23b**	B1 (2.5% sucrose)	**7.25**
A2 (2-day fermentation)	**7.28b**	B2 (5.0% sucrose)	**7.27**
A3 (3-day fermentation)	**7.26b**	B3 (7.5% sucrose)	**7.31**
Control/KA (no fermentation, 0 days)	**7.51b**	B4 (10% sucrose)	**7.24**
		KB/Control (no sucrose fermentation 0%)	**7.51**

Note: Figures followed by the same letter in the same column indicate no significant difference according to the 5% BNJ test

Based on Table 2, the AP treatment (5-day farmer fermentation of fresh cocoa pods) produced the highest moisture content of 10.84%, which was significantly different (notation a) compared to all other treatments (A1, A2, A3, and Control), which showed notation b with a range of 7.23–7.51%. The high moisture content in AP is thought to result from the intensity of microbial activity during the 5-day fermentation of fresh beans with full pulp. The degraded pulp released fermentation fluid (sweatings), which increased the moisture content in the beans.

This pattern is consistent with the findings of Sigalingging et al., (2020), who reported that the moisture content of cocoa beans increased by approximately 2.13% from the first to the second day of fermentation, then decreased by 0.99% on the third day and remained nearly constant on the fourth and fifth days. Under AP conditions, pulp content was higher than in rehydrated dry beans (treatments A1–A3), resulting in greater water release during fermentation.

Treatments A1 (1 day), A2 (2 days), A3 (3 days), and Control/KA (no fermentation) yielded moisture contents ranging from 7.23% to 7.51%, all of which were below the maximum limit of SNI 2323:2008 of 7.5%. Zainuddin & Marzuki, (2024) confirmed that moisture content is a primary general requirement in cocoa bean quality standards, and beans with moisture content exceeding 7.5% are highly susceptible to fungal growth during storage. Similarly, the A1–A3 and Control treatments showed that, after the dry bean refermentation process, the final moisture content after drying was relatively similar and remained within a safe range. Sucrose concentration had no significant effect on moisture content, as its role is primarily as a biochemical substrate for microbes, rather than a direct modifier of the bean's moisture content.

pH Values of Fermented Cocoa Beans

Effect of Fermentation Time and Interaction on pH

The pH parameter exhibited the most complex influence among all observed parameters. Based on Table 1, fermentation time had a highly significant effect (**), sucrose concentration had a significant effect (*), and the interaction between the two had a highly significant effect (**) on cocoa bean pH. The results of the 5% BNJ test with an interaction table are presented in Table 3.

Table 3. pH Values of Re-fermented Cocoa Beans Based on the Interaction of Fermentation Time × Sucrose Concentration (5% BNJ Test).

Fermentation	BP	B1 (2.5%)	B2 (5.0%)	B3 (7.5%)	B4 (10%)	KB
AP	4.43a A	-	-	-	-	-
A1	-	5.50ab AB	6.33a A	5.01b B	5.37ab B	-
A2	-	6.24a A	5.01b B	5.01b B	5.67ab AB	-
A3	-	6.21a A	5.17b B	6.05a AB	5.38ab AB	-
KA	-	-	-	-	-	6.90a

Note: Identical lowercase letters within a column and identical uppercase letters within a row indicate no significant difference according to the BNJ 5% test

Note:
AP : (5-day fermentation by farmers) BP : (farmer-fermented from fresh cocoa pods)
A1 : (1-day fermentation) B1 : (2.5% sucrose)
A2 : (2-day fermentation) B2 : (5,0% sucrose)
A3 (3-day fermentation) B3 : (7.5% sucrose)
Control/KA (no fermentation, 0 days) B4: (10% sucrose); Control (KB)(no sucrose fermentation, 0%)

The AP treatment with BP produced the lowest pH, namely 4.43 (notation a). This value is below the ideal range for the chocolate industry, which requires bean pH to be close to 5 or higher (Mulato, 2019). The low pH in the AP+BP treatment was caused by the accumulation of organic acids resulting from a 5-day fermentation of fresh beans with full pulp. During fermentation, lactic acid bacteria degrade pulp sugars into lactic acid, followed by acetic acid bacteria, which oxidise ethanol into acetic acid that seeps into the beans (Gusriani & Koto, 2022)

In the active re-fermentation treatment, there were significant differences between sucrose concentrations at each fermentation time point. In A1 (1 day of refermentation), treatment B2 (5.0% sucrose) produced the highest pH of 6.33, which was not significantly different from B1 (5.50, notation ab) and B4 (5.37, notation ab), but was significantly different from B3 (5.01, notation b). In A2 (2 days), B1 produced the highest pH of 6.24 (notation a), which differed significantly from B2 (5.01, notation b) and B3 (5.01, notation b). In A3 (3 days), B1 and B3 again showed the highest pH values (6.21 and 6.05), which did not differ significantly from one another.

This pattern indicates that adding sucrose at low–moderate concentrations (B1, 2.5%) tends to yield higher, more stable pH values across various fermentation time points. This phenomenon can be explained by yeast invertase hydrolyzing sucrose into glucose and fructose, which serve as the fermentation

substrate. At high sucrose concentrations (B3, 7.5%, and B4, 10.0%), excessive osmotic pressure can inhibit optimal growth of certain microbial strains, resulting in uneven production of organic acids (Rizqiati et al. 2021; Tulnafsi et al. 2025).

The Control treatment/KA (without additional fermentation, only storage) yielded the highest pH of 6.92. This value technically meets the standard for good fermentation (pH > 5.0), but cannot be immediately interpreted as perfect fermentation, as the high pH may also be due to insufficient acid production from the absence of active fermentation treatment. Sigalingging et al., (2020) explain that the pH of well-fermented cocoa beans generally decreases first during days 1 to 4 due to the accumulation of lactic and acetic acids, then rises again on day 5 as acidification activity decreases. The clear interaction between fermentation time and sucrose on pH confirms that these two factors act synergistically; therefore, determining the optimal sucrose concentration must always take into account fermentation duration.

Fermentation Index (FI) of Re-fermented Cocoa Beans

The Effect of Sucrose and Fermentation Time on the FI

The Fermentation Index (FI) is the most representative parameter for assessing the biochemical quality of cocoa bean fermentation. Based on the analysis of variance (Table 1), sucrose concentration had a highly significant effect (**), fermentation time had a significant effect (*), and the interaction between the two had a significant effect (*) on the FI. The dominance of sucrose over fermentation time on the FI parameter is a finding of practical importance. The results of the 5% BNJ test with an interaction table are presented in Table 4.

Table 4. Fermentation Index of Re-fermented Cocoa Beans Based on the Interaction of Fermentation Time × Sucrose Concentration (5% BNJ Test).

Fermentation	BP	B1 (2.5%)	B2 (5.0%)	B3 (7.5%)	B4 (10%)	KB
AP	1.47a A	-	-	-	-	-
A1	-	0.65b A	0.63a A	0.73a A	0.69a A	-
A2	-	0.83a A	0.68a B	0.70a B	0.66a B	-
A3	-	0.72b A	0.69a A	0.75a A	0.69a A	-
KA	-	-	-	-	-	0.44a

Note: Identical lowercase letters within a column and identical uppercase letters within a row indicate no significant difference according to the BNJ 5% test.

Note :
AP : (5-day fermentation by farmers) BP : (farmer-fermented from fresh cocoa pods)
A1 : (1-day fermentation) B1 : (2.5% sucrose)
A2 : (2-day fermentation) B2 : (5,0% sucrose)
A3 (3-day fermentation) B3 : (7.5% sucrose)
Control/KA (no fermentation, 0 days) B4: (10% sucrose); Control (KB)(no sucrose fermentation, 0%)

The AP+BP treatment produced the highest IF (1.47). An IF value exceeding 1.0 indicates over-fermentation in farmers' seeds derived from fresh fruit that underwent a full 5-day fermentation without additional substrate. Balittri (Fahrurrozi et al, 2020) emphasizes that an IF of 1 signifies perfect fermentation; thus, values above 1 may indicate damage to seed components due to prolonged and excessive enzymatic activity. Pitaloka et al., (2025) also note that excessively prolonged fermentation can lead to excessive degradation of polyphenols and proteins, thereby reducing the final quality of the seeds.

In the dry seed re-fermentation treatments (A1, A2, A3), IF values ranged from 0.63 to 0.83 — lower than the ideal value of 1, yet significantly better than the Control treatment (0.44), which indicated the least complete fermentation conditions. This confirms the success of dry bean re-fermentation in promoting internal biochemical changes in the beans, although it does not fully match the fermentation of fresh beans. Apriyanto et al., (2018; Widianto et al., 2013.) reported that the fermentation of dry cocoa beans without prior fermentation, utilizing an additional carbon source (palm sap), had a significant effect on the fermentation index, indicating that the availability of external substrate is a key driver of the IF.

At fermentation level A2 (2 days), treatment B1 (2.5% sucrose) produced the highest IF of 0.83 (notation a), which differed significantly from B2 (0.68, notation b), B3 (0.70, notation b), and B4 (0.66, notation b). At A1 (1 day) and A3 (3 days), the differences between B1 and B2–B4 were not significant, except that B1 showed a lower b-notation than A2 at the same level. In the rows (between fermentation time levels at the same sucrose level), for B1, treatment A2 (0.83) differed significantly from A1 (0.65) and A3 (0.72), indicating that the A2 × B1 combination was the most optimal for promoting the fermentation index toward the ideal value.

The advantage of B1 (2.5% sucrose) over higher sucrose concentrations in producing the highest IF at many fermentation levels can be explained physiologically. At sub-optimal substrate concentrations,

yeast and lactic acid bacteria work efficiently to produce organic acids that permeate into the seeds and induce enzymatic reactions forming flavor precursors. Excessively high sucrose concentrations (B3 and B4) likely suppress the activity of some microbes via osmotic effects, so that the fermentation rate does not increase proportionally with substrate addition (Rizqiati et al., 2021). This supports the importance of optimizing sucrose concentration to avoid excess in the practice of dry cocoa bean refermentation.

Weight of 100 beans (g) after refermentation

Effect of Fermentation Time on the Weight of 100 Beans

Based on the analysis of variance (Table 1), fermentation time had a highly significant **(**)** effect on the weight of 100 beans, whilst sucrose concentration (tn) and its interaction (tn) had no significant effect. The mean weight of 100 beans is presented in Table 5. It should be noted that although the analysis of variance indicated a highly significant effect, the BNJ test results did not display letter notation for these data; therefore, the interpretation focuses on the patterns of trends between treatments.

Table 5. Mean Weight of 100 Re-fermented Cocoa Beans by Treatment.

Treatment Fermentation Time	Weight of 100 Beans (g)	Sucrose Treatment	Weight of 100 Beans (g)
AP (farmer fermentation, 5 days)	223	BP (fermentation of fresh cocoa beans by farmers)	223
A1 (1-day fermentation)	216	B1 (2.5% sucrose)	219
A2 (2-day fermentation)	218	B2 (sucrose 5.0%)	217
A3 (3-day fermentation)	220	B3 (sucrose 7.5%)	218
KA/Control (no fermentation)	221	B4 (sucrose 10.0%)	223
		KB/Control (without sucrose)	221

Note: Data on the weight of 100 seeds is presented without BNJ notation. SNI 2323:2008 classification: Grade A (≤85 seeds/100g), B (86–110 seeds/100g), C (>110 seeds/100g).

Note:
AP : (5-day fermentation by farmers) BP : (farmer-fermented from fresh cocoa pods)
A1 : (1-day fermentation) B1 : (2.5% sucrose)
A2 : (2-day fermentation) B2 : (5,0% sucrose)
A3 (3-day fermentation) B3 : (7.5% sucrose)
Control/KA (no fermentation, 0 days) B4: (10% sucrose); Control (KB)(no sucrose fermentation, 0%)

Overall, the weight of 100 seeds across all treatments ranged from 216 to 223 g. This value indicates that each seed weighs approximately 2.16–2.23 grams on average. The AP and BP treatments showed the highest weight of 100 seeds (223 g), whilst A1 and B2 showed the lowest values (216–217 g). The trend of decreasing weight in the active re-fermentation treatments (A1–A3) compared to AP can be attributed to weight loss (sweating) during fermentation, as fluids resulting from pulp degradation and microbial metabolism are released from the bean mass. Referring to SNI 2323:2008, the classification of cocoa bean quality based on bean size is divided into Grade A (≤85 beans per 100 grams), B (86–110 beans per 100 grams), and C (>110 beans per 100 grams). With an average weight of 100 beans at around 216–223 grams, every 100 grams contains fewer than 50 beans; therefore, all treatments fall within Grade A (large bean size) according to SNI 2323:2008 (BSN, 2008; Fahrurrozi et al, 2020; Hatmi & Rustijarno, 2012). (Pitaloka et al, 2025) reported that a count of 95 seeds per 100 grams still falls within Grade A, indicating that seeds with a relatively high weight automatically fall into the highest quality category based on size. No significant effect; the sucrose concentration on the weight of 100 seeds confirms that the sucrose substrate plays a role in biochemical aspects (pH, IF) rather than in increasing the physical mass of the seeds. The highly significant effect of fermentation time on the weight of 100 seeds is likely related to changes in the water composition within the seeds following fermentation and to differences in drying conditions across treatments. More intensive fermentation (AP, 5 days) produced beans with greater weight due to more organic components retained after partial water loss, whereas short-term re-fermentation (A1, 1 day) resulted in less weight loss, yet the final beans were lighter. (Zainuddin & Marzuki, 2024) also noted that variations in drying time significantly affect the final weight of cocoa beans, underscoring the relationships among fermentation duration, the drying process, and the resulting physical characteristics of the beans.

Discussion

Holistically, this study's results reveal two distinct yet complementary patterns of influence. Firstly, fermentation time predominantly controls the physical parameters of the beans (moisture content and weight of 100 beans), as changes in these parameters are driven by mechanical and hydrological activities during fermentation — pulp degradation, sweating release, and changes in bean tissue structure over time. Secondly, sucrose selectively influences biochemical parameters (pH and IF) because it is directly fermented by yeast and lactic acid bacteria, producing organic acids that alter the chemical conditions within the seed.

The highly significant interaction between fermentation time and sucrose on pH, as well as the significant interaction on IF, indicates that these two factors do not act independently on the biochemical aspects of fermentation. In other words, the effectiveness of sucrose in lowering pH and increasing IF depends on the duration available for microbes to metabolize the substrate. Without sufficient fermentation time, adding sucrose will not result in optimal biochemical transformation in the seeds. Conversely, without the availability of additional substrates such as sucrose, a longer fermentation time alone is insufficient to optimally drive biochemical processes in dried seeds that have lost their natural pulp.

Treatment A2 × B1 (2-day fermentation + 2.5% sucrose) consistently demonstrated the best performance for the IF (0.83) and pH (6.24) parameters, both of which approached ideal values without resulting in excessively acidic conditions. These conditions reflect an optimal balance between substrate availability and fermentation duration for rehydrated dry beans. These results are consistent with Apriyanto & Tp, (2017) who concluded that fermenting dry cocoa beans with an appropriate external carbon source can significantly improve the fermentation index, bringing it close to the standard value for perfect fermentation.

The Control Treatment (no fermentation, 0 days) consistently yielded the lowest IF (0.4367) with a moisture content approaching the upper limit of the SNI standard (7.51%), confirming that without active fermentation treatment, cocoa beans are unable to achieve the necessary biochemical transformation to produce adequate precursors of chocolate flavor. This supports the statement by Nengsi et al., (2025) that unfermented or under-fermented cocoa beans have a strong bitter taste and do not meet international quality standards for raw materials in premium chocolate products.

CONCLUSIONS

Fermentation time primarily influences the physical properties of cocoa beans (moisture content and weight), whilst sucrose concentration more strongly affects biochemical properties (pH and fermentation index). The optimal combination was achieved with a 2-day fermentation at 2.5% sucrose (A2 × B1), yielding bean quality closest to ideal conditions. Re-fermentation was shown to improve the quality of cocoa beans compared to unfermented beans, offering potential as a quality-enhancement solution at the farmer level.

Acknowledgements: The researchers would like to thank Politeknik Negeri Lampung for funding the research through DIPA, in accordance with the Research Implementation Agreement for Fiscal Year No. 180.2.52/PL15/PP/2025 dated 8 July 2025. We would also like to thank Prof. Sri Mulato (Coffee and Cocoa Training Center/https://www.cctcid.com/) for her ideas and expert input on cocoa fermentation, which contributed to the development of this research.

Authors' Contributions: Analianasari and Sri Mulato designed the study. Giffary Pramafisi Soeherman carried out the laboratory work and analyzed the data. Analianasari and Dayang Berliana wrote the manuscript. All authors read and approved the final version of the manuscript.

Competing Interests: The authors declare that there are no competing interests.

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