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Application of Ohmic Heating Technology on Cocoa Beans Fermentation: Design, Physicochemical Properties and Techno-Economic Analysis

Angky W. Putranto[1,*], Olivia P. Nugroho[2], Wardatul Maulidah[1], Risaldi[3], Ivan H. E. Saputro[2], Alif W. D. A. Mulyono[2]

[1]Bioprocess Engineering Department, Faculty of Agricultural Technology, Universitas Brawijaya, 65145, Malang, Indonesia
[2]Agroindustrial Engineering Department, Faculty of Agricultural Technology, Universitas Brawijaya, 65145, Malang, Indonesia
[3]Agricultural and Biosystem Engineering Department, Faculty of Agricultural Technology, Universitas Brawijaya, 65145, Malang, Indonesia

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Abstract The fermentation process is the most essential step in the processing of cocoa beans (*Theobroma cacao* L.) since the chocolate quality is depended from this process. In general, the common conventional fermentation of cocoa beans using Wooden Box Fermentation (WBF) takes 6-8 days. The long duration and no controlling process during fermentation decreased the quality of fermented beans. To overcome this drawback, the Ohmic Reactor Fermentation (ORF) has been investigated for accelerating the fermentation process through an optimum condition for the growth of microorganism. Therefore, the objectives of this study were to design an ohmic heating-assisted reactor and evaluate the fermented beans according to its physical, chemical and biological properties. In this study, fermented beans from the ORF process were also compared with WBF processes, from both the physico-chemical properties and techno-economic aspects. The results showed that the reactor design successfully fermented cocoa beans (99.97%) with a shorter fermentation period than the WBF process. Moreover, the ORF process produces good-quality cocoa beans which are in line with the premium grade standard used in Indonesia, Malaysia, the Philippines and globally. The ORF process is also feasible to implement based on the techno-economic aspects. Despite having higher operational costs compared to the WBF process, the good quality cocoa from ORF has a higher selling price and generates a higher total revenue. Therefore, these research findings can be developed on a larger scale and utilized optimally by the small and medium-scale cocoa industry, especially in Indonesia, to produce premium-quality cocoa beans through a good fermentation.

Keywords Cocoa Beans, Fermentation, Ohmic Heating, Properties, Quality Standard

1. Introduction

Cocoa is a plantation crop that is used as the main ingredient in chocolate production. Cocoa is also a very important plantation commodity in the world with a total cocoa production of 5.1 million tons per year [1]. Cocoa beans are one of the abundant plantation products in Indonesia. Based on Indonesian statistic database, the number of cocoa productions in 2015 was 24,803 tons and in 2019 cocoa production in East Java increased to 28,476 tons [2]. Moreover, Indonesia is the largest producer of cocoa beans in the world with a total production of 200 thousand tons of cocoa beans per year [3]. The cocoa beans processing requires several stages to become a good quality derivative product. The fermentation process is one of the post-harvest processes that must be carried out to form a quality chocolate taste. This process plays an essential role in the chocolate processing industry since the biochemical, enzymatic, and microbiological reactions occur, and can affect the economic value of cocoa beans [4].

In general, small and medium enterprises (SMEs) producing cocoa in Indonesia used wooden boxes for cocoa beans fermentation process. Since it was conventionally and without any treatment, this process takes 6 to 8 days [5] and mostly damages the beans or causes defects in the cocoa beans after fermentation. The presence of slaty beans, larvae, the growth of shoots on cocoa beans, and mold at the end of the fermentation process causes this defect. According to Junior et al. [6], the cocoa bean fermentation process is strongly influenced by temperature conditions during the process, where the optimal temperature for microorganisms to carry out the fermentation process is 42-45 ℃. Therefore, it was necessary to use a technology such as ohmic heating which maintains the temperature during the fermentation process. The optimum fermentation temperature with ohmic heating technology can be achieved in a short time with a fast temperature distribution and uniform heating [7]. Ohmic heating is the process of passing electric current through materials for heating purposes. Food products that are processed in an ohmic system act as an electrical resistor that is heated through the dissipation of electrical energy. The heating process using ohmic heating was first introduced by James Prescot Joule who stated that this method can be used to process food products in liquid or solid form because both can conduct electricity [8]. The ohmic heating application for the cocoa beans fermentation process was able to accelerate the fermentation process of cocoa beans in a few minutes. This technology can reduce the lag phase of microorganism growth so that the fermentation process can take place more quickly [8].

Nonetheless, the exploration of fermented cocoa beans with ohmic heating technology still has gaps and no study has been found related to through testing such as physical, chemical, and biological testing of fermented cocoa beans. Moreover, an economic feasibility analysis in the application of ohmic technology is also still a demand which is the basic concept of this research. Therefore, this research aim is to design a reactor for cocoa beans fermentation and to analyze the physical, chemical, and biological of fermented beans as well as evaluate its techno-economics. This study will also compare the results of the design with the common method that has been applied in SMEs. The results of the research are expected to be applied comprehensively to all cocoa processing, especially for the small and medium-scale cocoa industries in Indonesia to improve the quality of local cocoa beans.

2. Materials and Methods

2.1. Reactor Design

The design of the cocoa bean reactor as shown in Figure 1. This reactor chamber made of clear glass material that has a thickness of 0.5 cm. The glass material for reactor chamber is aimed to easier for visual observation during the fermentation, aseptically material as well as good insulator which do not conduct heat and electricity. The reactor chamber has 30 cm of high and diameter of 26 cm, in which the maximum capacity of 7 kg cocoa beans. The reactor is equipped with ohmic heating technology which is used to accelerate the fermentation process through the steady temperature (42-45 ℃) [6]. The ohmic heating electrodes are designed using stainless steel 304 material with a circular shape that has a diameter of 20 cm. This material used since it was a food grade and not easily rusted in prolonged use. The ohmic electrode was positioned at the base of the chamber for the anode and the top of chamber for the cathode. They are connected to the control box. The cathode plate connected to the chamber cover with four springs (10 cm length) and isolator so the electrodes can be in perfect contact with the cocoa beans. Both plates will be electrified with a voltage of 8.8 V/cm until it reaches the set point of fermentation temperature.

The J-type thermocouples are used as temperature sensors which are placed at three points on the chamber wall. This aims to ensure the temperature distribution during fermentation. This thermocouple has a temperature detection susceptibility between 0 to 750 ℃. The aeration system in the reactor is designed by using a DC fan (12 volt). The function of this fan is not only as a supplier of oxygen in the initial process of fermentation, but also to release heat when the temperature in the chamber exceeds the set point value, thereby reducing the occurrence of over-heat during fermentation. To support the working system of this reactor, several instrumentations are attached to the control box including a timer for fermentation time control, current display, voltage display, temperature display, and temperature control. The vertical chamber reactor, ohmic heating electrode, and temperature sensor configuration were adopted from Supratomo et al. [8] study and modified by adding a waste liquid removal faucet and the aeration system at the top of the reactor.

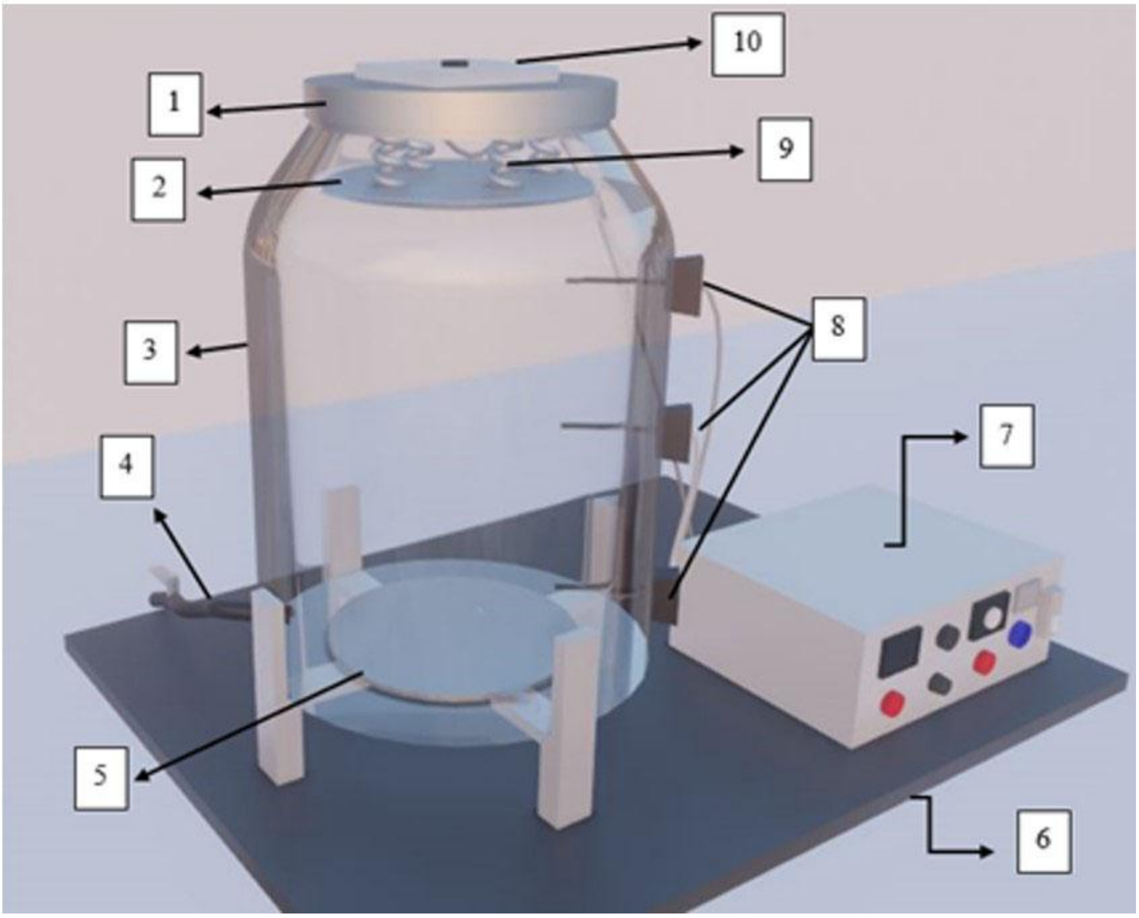

Figure 1. The design of cocoa beans reactor. Cover of chamber (1), cathode (2), fermentation chamber (3), faucet (4), anode (5), wood-based plate (6), control box (7), temperature sensors (8), spring for electrode (9) and DC fan (10)

2.2. Reactor Performance Testing

Testing the performance of the reactor was carried out to determine the time required to reach the optimum temperature and the required electrical power during the fermentation of cocoa beans using ohmic heating. The test is carried out by calibrating it first using water to ensure the electrode can work properly. The fermentation chamber filled with water and then given an electric current until the temperature set point achieved. During the calibration process, the temperature changes from the ambient temperature to the set point temperature (43 ℃) as optimum temperature for cocoa fermentation was recorded. After confirming that the ohmic electrode and other components are working properly to achieve set point temperature, a direct fermentation process is carried out using 7 kg of cocoa beans. The measurement of electrical power required during the fermentation process is carried out by recording the value of the electric current and the electricity resistance of each increase in fermentation temperature by 1 ℃, which has been listed on the display. The electrical power used during the fermentation process can be determined by the following equation:

$$P = V\ x\ I \quad (1)$$

Where P is power, I is current, and V is electric voltage. The total electrical power obtained is the power needed to reach the optimum temperature. Therefore, to get the value of the energy during the fermentation process (kJ/kg), the total power of reactor was multiplied with total hours during the fermentation process and divided by total mass of beans.

2.3. Fermentation Process

The cocoa bean processing process consists of several steps, namely the cocoa bean preparation step, the fermentation step, and the post-fermentation step. The details of those steps are presented in Figure 2. The sample preparation step includes harvesting, sorting, and breaking cocoa pods. In this study, cocoa beans were obtained from farmers in Mojokerto, East Java, Indonesia. The harvested cocoa pods are 5 months old with yellowish color characteristics with fruit lengths reaching ±25 cm. The sorting of cocoa pods conducted by separating good cocoa pods from those that are attacked by pests. The good quality cocoa pods are then broken down to get cocoa beans.

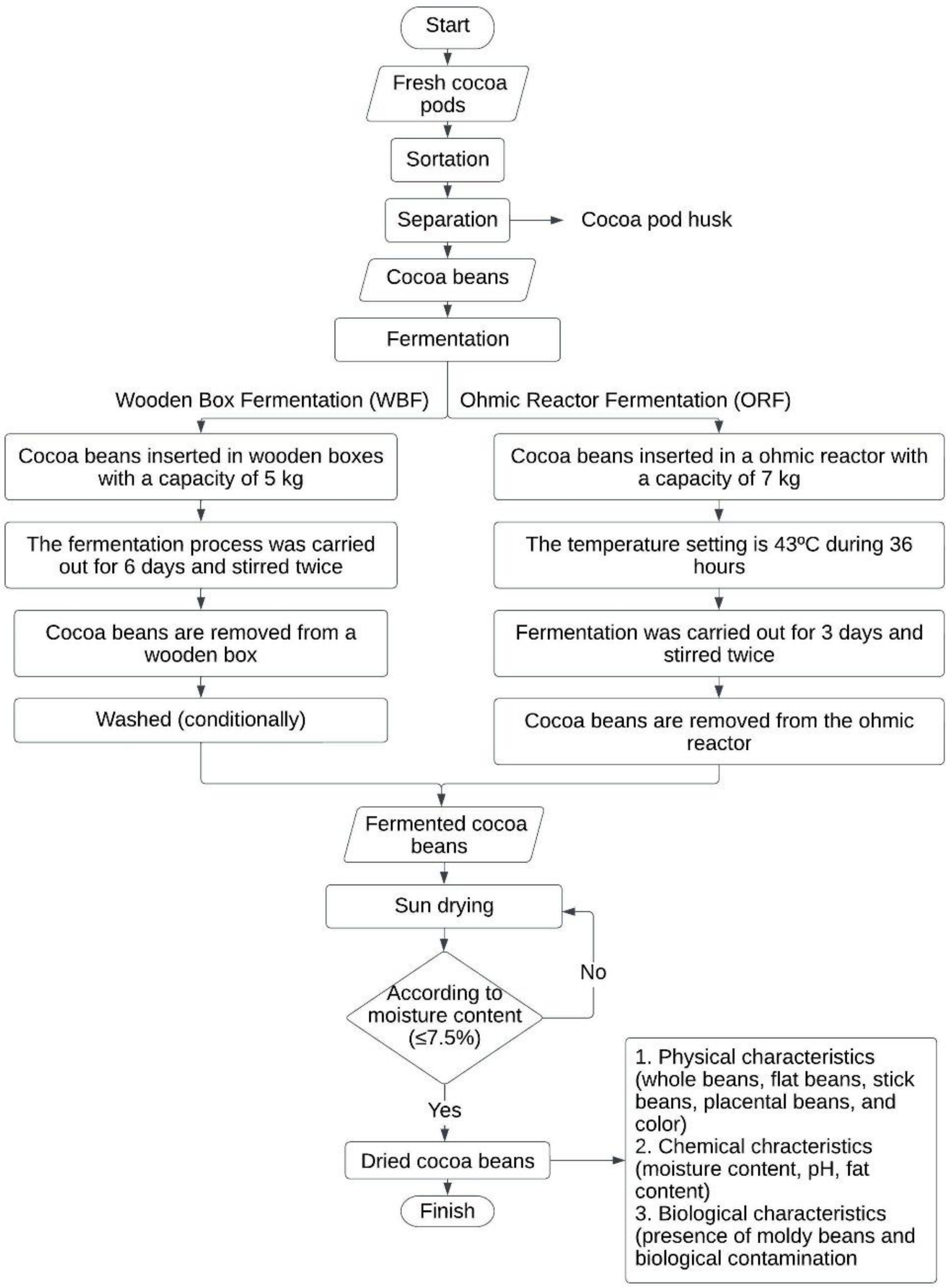

Figure 2. Cocoa beans fermentation procedure using ORF and WBF methods

In the second step, the cocoa beans fermentation process was divided into two methods. The first method is conventional Wooden Box Fermentation (WBF) as common fermentation method in local cocoa farmers and the second method is Ohmic Reactor Fermentation (ORF). For WBF process, 5 kg of harvested cocoa beans were inserted in wooden box and covered with leaves until the end of fermentation. While for ORF process, 7 kg of cocoa beans inserted in ohmic reactor and ensured both electrode surfaces reach the cocoa beans thoroughly. Then the temperature was set at 43 ℃ and the ohmic duration was 36 hours. During fermentation, the WBF and ORF processes are stirred manually twice, to ensure that all beans are fermented thoroughly. Fermentation is stopped when the pulp has separated and the cocoa beans appear brown in color. Based on these indicators, the WBF and ORF process were conducted for 6 and 3 days, respectively.

For post-fermentation, the fermented cocoa beans were dried under the sun until the moisture content reached 7.5%

according to the standard requirement. Then the dried cocoa beans were analysed for their physical, chemical, and biological properties.

2.4. Properties Analysis of Fermented Cocoa Beans

The fermented cocoa beans produced from WBF and ORF will be analyzed on the physical, chemical, and biological properties as well as compared with fermented cocoa beans standardization from Indonesian National Standard 2323-2008 [9], ISO 2451:2017 [10], Philippine National Standard [11], and Malaysia Standard [12].

2.4.1. The Physical Properties

Testing the physical characteristics of cocoa beans includes testing the shape of the cocoa beans and the color of the cocoa beans based on the cut-test method of the Indonesian National Standard [9]. The cut-test method is also used to measure the level of fermentation achieved in cocoa processing industries [8]. Testing the shape of cocoa beans is done by direct observation of dry fermented cocoa beans. The color test of the bean chips was carried out using a longitudinal cut test in the center of 300 fermented dry cocoa beans which were then classified into chip colors. The fermented beans have fully brown color, while for unfermented beans have purple or gray color (slaty beans). The percentage of the fermented beans classification is calculated using the formula:

- % Fermented beans

$$= \sum \frac{brown\ beans}{Cocoa\ beans\ accumulation} \times 100\% \quad (2)$$

- % Unfermented beans

$$= \sum \frac{Unfermented\ beans}{Cocoa\ beans\ accumulation} \times 100\% \quad (3)$$

2.4.2. The Chemical Properties

Testing of the chemical characteristics of cocoa beans including moisture content, fat content, and pH of cocoa beans was carried out based on the method of the Indonesian National Standard [9]. The moisture content test was carried out using a sample of cocoa nibs which were ground and dried at a temperature of 100-103 ℃ for 16 hours and the weight of the sample was weighed. The fat content test was carried out using hydrolysis and soxhlet extraction methods. The pH test was carried out using a sample of 10 g of nibs powder dissolved in 90 mL of 70-80 ℃ distilled water.

2.4.3. The Biological Properties

Testing the biological properties test of cocoa beans was carried out based on the method of the Indonesian National Standard [9]. The test was carried out by observing the biological contaminants in the cocoa beans after the fermentation process until the dried beans were stored for 20 days. This storage time was chosen since mold or biological contaminants started growing on the cocoa beans [13]. The percentage of moldy cocoa beans is calculated using the formula:

$$\%\ \text{Moldy beans} = \frac{Moldy\ beans}{Total\ number\ of\ beans\ cut} \times 100\% \quad (4)$$

2.5. Techno-economic Analysis

2.5.1. Technical Analysis

The technical feasibility aspect measured from three criteria, such asconstruction, operating methods, and product results [14]. Construction feasibility parameters are how the reactor can accommodate well and the durability of the constituent materials. The operating method parameters determine the ease of reactor use to operate all fermentation condition parameters and the reactor ability to maintain the cocoa beans during the fermentation process. The last but not least, product feasibility parameters are assessed based on the criteria for fermented beans according to the standards used as described in sub-chapter 2.4.

2.5.2. Economic Analysis

The economic feasibility analysis in this study conducted on assessing the design of an ohmic heating reactor in cocoa beans processing is feasible or not from an economic aspect. In order to be able to calculate the economic analysis according to actual conditions, the ohmic reactor design has been applied to the fermentation process in one of the medium-sized cocoa processing industries in East Java, Indonesia. Observations and economic calculations carried out in that industry start from the process of harvesting cocoa to selling dried cocoa beans. The economic analysis was evaluated by using several essential aspects that determine the feasibility value, such as B/C ratio, payback period, Net Present Value (NPV), Internal Rate of Return (IRR), and Break Even Point (BEP).

Since the economic analysis is more emphasizing on the fermentation process (WBF and ORF), the economic calculations for other processes such as the drying process are considered same. However, the selling price of dry cocoa which is used as an economic calculation is also in accordance with the actual sales conditions carried out by the industry. In addition, the policy factors such as subsidies, authorizations or carbon credits, and other environmental aspects which will affect the economic evaluation, were not considered in this study. The benefit-cost ratio is the result of a comparison between revenues and total costs incurred. The B/C ratio can be calculated by the following equation:

$$B/C = \frac{total\ revenue}{total\ cost} \quad (5)$$

From the equation above, the investment was considered feasible if B/C more than 1. Otherwise, the investment is not feasible while the B/C less than 1. The Payback Period (PP) is used to determine the time required to break even from the initial investment [15]. The PP is measured using following formula:

$$PP = \frac{total\ investment}{total\ revenue} \quad (6)$$

NPV serves to measure the company's opportunity to manage investments until the currency value changes and has an impact on the company's cash flow [16]. The NPV calculation using the following formula:

$$\mathrm{NPV} = \mathrm{PW_R} - \mathrm{PW_E} \quad (7)$$

The result of the NPV calculation will determine the following 3 conditions such as:

- NPV > 0, the investment was profitable
- NPV < 0, the investment was not profitable
- NPV = 0, the investment was at the break-even point conditions

In addition, it was important to calculate the IRR to determine the efficiency level of an investment or to assess investment projections [17]. The IRR calculation used the following equation:

$$IRR = i_1 + \frac{NPV_1}{NPV_1 + NPV_2}(i_2 - i_1) \quad (8)$$

The results of the NPV calculation will indicate the following 3 conditions such as:

- IRR > bank interest, then the investment was feasible
- IRR < bank interest, then the investment was not feasible
- IRR = bank interest, then the investment was at the break-even point

The last but not least, a BEP value was useful for determining the minimum number of sales to avoid losses [18]. The BEP was calculated using the following formula based on the amount of production and the total costs used, which are called $\mathrm{BEP_{production}}$ and $\mathrm{BEP_{price}}$, respectively.

$$BEP_{production} = \frac{Total\ cost}{Selling\ price} \quad (9)$$

$$BEP_{price} = \frac{Total\ cost}{Total\ Production} \quad (10)$$

3. Results and Discussion

3.1. The Reactor Realization

The reactor design has been successfully fabricated and realized for the cocoa beans fermentation process in a short time based on ohmic heating. This reactor aims to shorten the fermentation time by conditioning the temperature at the beginning of the fermentation. The temperature will be maintained during the fermentation process at 43 ℃ using ohmic heating. The ohmic heating depends on the direct generation of heat in the product volume and volumetric heating. Therefore, this heating method has a high coefficient of performance, almost all of the input electrical energy is converted into heat energy [19]. The controlled temperature at the beginning of fermentation will shorten the lag phase of microorganisms which results in faster fermentation process. The temperature sensor will detect the real temperature during the fermentation process with the set point at 43 ℃ and the input results from the three sensors will be displayed on the screen. When the input temperature exceeds the set point value, it will provide a signal to the control system so that the ohmic electrode current is turned off and the aeration system is turned on. During the fermentation process, the white pulp that covers the cocoa beans turns into a liquid and accumulated on the bottom of the reactor as the residual fermentation. Therefore, the reactor tube designed is equipped with an open and closed valve to drain the liquid waste out and accommodate it to be processed further into other useful products.

3.2. Reactor Performance

Based on the performance test results, the time required to achieve the optimum fermentation temperature (43 ℃) in ohmic reactor from ambient temperature was 70 minutes. Then the reactor temperature was maintained at 43 ℃ until the fermentation completed. The detailed temperature rise from ambient to optimum temperature can be seen in Fig. 3A. Based on Fig. 3A., it can be concluded that ohmic heating time and temperature are positively correlated which is indicated by the R^2 value of 0.994. This is also in line with the Supratomo et al study [8], where the relationship between temperature and time using ohmic heating had an R^2 of 0.998. However, the time they need to reach the set point temperature of 50 ℃ was 17 minutes with a low electric field strength of 5.97 V/cm. This is because the diameter of the electrode they used was wider (30 cm) than the diameter of the electrode used in this research reactor, which was 20 cm. The larger diameter ohmic electrodes are able to transfer heat energy more quickly to the material. Yet, the selection of the 20 cm electrode diameter is adjusted to the diameter of the reactor cover which is smaller than the reactor body. Where the width of the reactor cover is 21 cm, while the reactor body has a diameter of 26 cm.

In addition, the use of ohmic heating in ORF process is turned on and maintained at the set point temperature as the optimum temperature for the growth of the microbes involved. If there is an increase in temperature, then the DC fan will turn on automatically to keep the optimum fermentation temperature. Based on Fig. 3B, the DC fan equipped in reactor is successful to maintain the optimum temperature with the deviation is 1 ℃. During the ORF process, the ohmic electrode is electrified for 36 hours to accelerate the optimum temperature for the growth of *Lactobacillus* and *Acetobacter* which naturally exists in the cocoa beans in the first stage of the fermentation process. After the *Lactobacillus* and *Acetobacter* work optimally at the set point temperature, the next step is the fermentation process carried out by Lactic Acid Bacteria and Acetic

Acid Bacteria. In this phase, the bacteria will change the substrate aerobically and release heat energy to the system. Microbes and enzymes activity will be increased when the fermentation continued and will produce heat greater than the result of sugar oxidation during fermentation [20]. Therefore, in the second fermentation phase, ohmic heating is in off mode, while the DC fan remains on to support the aerobic process and to reduce the temperature when the heat accumulation from the fermentation process occurs. During this second phase, the fermentation temperature was monitored and the set point temperature was maintained until the end of the fermentation (72 hours) as shown in Fig. 3C.

Compared with WBF, the ohmic heating assisted fermentation is faster than conventional method (WBF). The length of fermentation time is influenced by the temperature and activity of natural microorganisms contained in it [7]. The use of ohmic heating technology functions as a heater in the initial fermentation process so that it is able to create optimum conditions for natural microorganisms and can accelerate the lag phase or the microbial adjustment phase of fermentation to take place earlier. In addition, the existence of an aeration system in ohmic heating reactor is able to keep the temperature inside the reactor was controlled. Thus, the temperature will always be in an optimal state so that the time required for fermentation becomes shorter [8].

The average power required during the ORF process (72 hours) is 336.97 watt. The large value of power is influenced by the magnitude of the electric current that has been set. The greater the electric current, the greater the power required so that the required power range is 250-500 watt. The energy needs during the ORF process is 1,213 kJ or 173.3 kJ/kg.

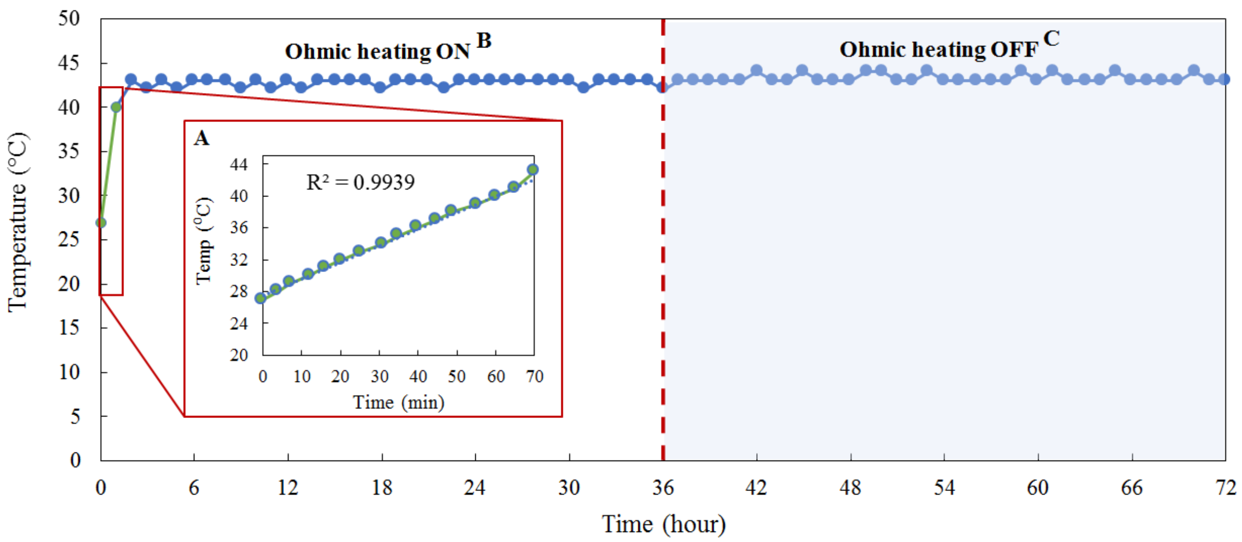

Figure 3. Temperature monitoring during fermentation. Set point temperature achieved (A), the ohmic heating and DC fan are ON mode (B), the ohmic heating is turned off and the DC fan is still running until the end of the fermentation period (C)

3.3. Physical, Chemical, and Biological Properties of Fermented Cocoa Beans

There are significant differences on the properties analysis of dried cocoa beans from WBF and ORF process as shown in Table 1. The quality characteristics of fermented cocoa beans from the WBF and ORF processes were also compared with the grade I (premium or highest grade) quality standards in each country such as Indonesia, Malaysia, Philippines and internationally (ISO). Based on several parameters according to the quality standard, the fermented cocoa from the ORF process have met on all the quality standards. Fermented cocoa beans undergo physical changes in this case the color of the beans. Where the change in color of cocoa beans after fermentation was caused by a decrease in the content of polyphenols (including anthocyanidins) which were oxidized and polymerized into insoluble high molecular weight compounds (tannins) [21].

During the fermentation process, an overhaul causes the pulp layer on the cocoa beans to disappear. This can minimize the presence of attached cocoa and placental cocoa beans. The number of attached seeds will decrease and the number of whole seeds will increase along with the fermentation time [22]. The WBF method has drawback on the bean's quality such as slaty beans (unfermented beans), germinated beans and moldy beans. The pulp layer is not completely removed and contaminated due to microorganism. This can happen due to uncontrolled temperatures and holes in wooden boxes that allowing other unwanted microorganisms from outside to play a role in the fermentation process. Fermentation of cocoa beans requires an optimum temperature for the natural microorganisms inside the beans can grow properly. Fermentation using ohmic heating is considered more effective because it can accelerate the lag phase of microorganisms so that the fermentation process can take a shorter time, namely 3 days.

Based on the results of color testing in Table 1, more slaty beans were found in the conventional fermentation process. Slaty beans indicate that the fermentation process is not perfect or that the fermentation that occurs is uneven in all beans. This can affect the quality of cocoa beans [8]. The slaty beans produced are affected by the fermentation temperature. The controlled fermentation temperature can minimize the content of slaty beans. To test the color of the peeled cocoa beans, a cut test was conducted on 300 cocoa beans for classification, namely fermented cocoa beans and slaty cocoa beans. However, for further research it is recommended to compare cocoa bean color testing using computer vision and artificial intelligence technology with an accuracy of 94% [21]. The classification results are calculated using the formula (2,3). In the fermentation process using ohmic heating technology (ORF), the content of slaty beans is only 0.3% and perfect cocoa beans are 99.97%. Perfect brown beans indicate that the cocoa beans have been completely fermented. This is because the temperature in the fermentation room is more controlled and the heat generated can be spread evenly throughout the material so that the fermentation of the material can be carried out perfectly. The appearance of fermented and unfermented cocoa beans can be seen in Figure 4. In the fermentation process using a wooden box (WBF), the content of slaty beans is 22.67% and perfect cocoa beans are 77.33%. These results indicate that the cocoa beans are not fully fermented with the discovery of slaty beans (purple). The appearance of the cut test results on cocoa beans can be seen in Figure 4.

Table 1. The Physical, Chemical and Biological Properties of Fermented Cocoa Beans

Indicator	WBF	ORF	Indonesia National Standard 2323-2008 [9]	ISO 2451:2017 [10]	Philippine National Standard 58-2007 [11]	Malaysian Standard 293-2005 [12]
Physical properties						
Unfermented beans (%)	22.67	0.03	Max. 3	Max. 3	Max. 3	≤ 3
Fermented beans (%)	77.33	99.97	≥ 97	≥ 97	≥ 97	≥ 97
Chemical characteristics						
Moisture content (%)	7.03	6.14	Max. 7.5	Max. 7.5	5 – 7.5	≤ 7.5
Fat content (%)	28.19	25.40	-	-	-	-
pH	5.15	5.27	-	-	-	-
Biological characteristics						
Moldy beans (%)	1.33	0	Max. 2	Max. 3	Max. 3	≤ 3
Biological contamination	larvae found	None	None	None	None	None

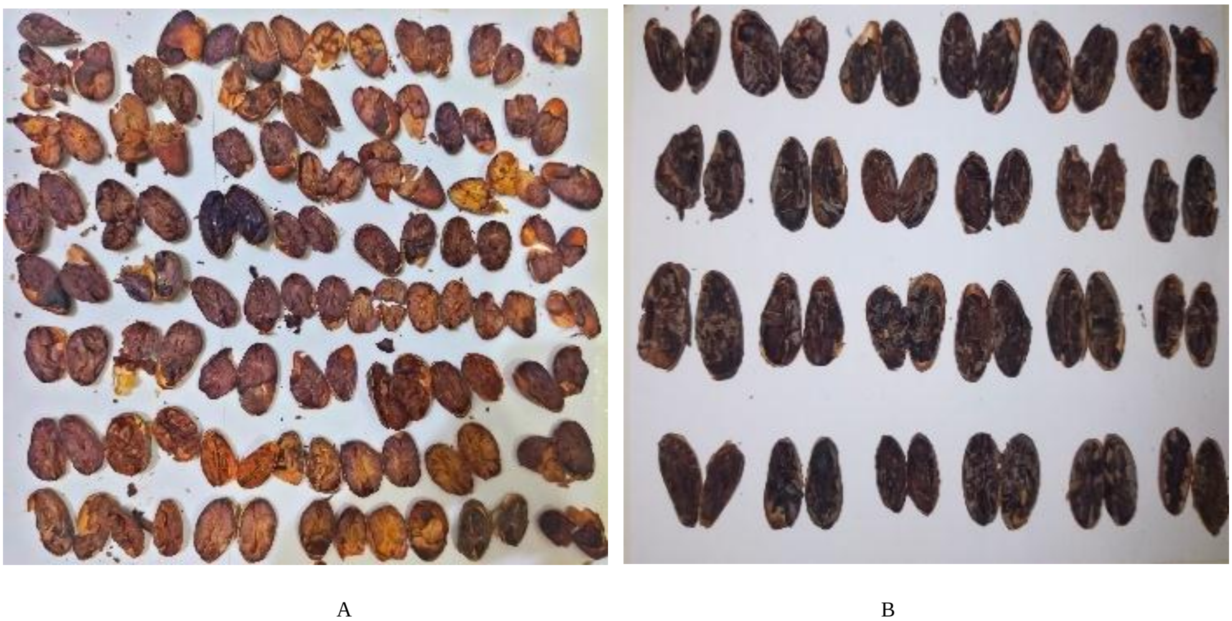

Figure 4. The cut test appearance of dried cocoa from the WBF process (A) and the ORF process (B)

For the moisture content parameters, as presented in Table 1, both dried beans (from WBF and ORF) have a moisture content that meets all standard (below 7.5%). However, the fermented beans from the WBF process have a higher moisture content than in the ORF process, which was 7.03%. This condition is due to the white-pulp layer covering the beans cannot be completely separated during fermentation. Hence, the water molecules inside the seeds are trapped and difficult to evaporate during the drying process. While, the fermented cocoa beans from ORF process have a lower moisture content of 6.14%, since the pulp layer has completely removed and the drying rate was increased. The destruction of the pulp from cocoa beans causes the large pores of the beans and it will ease the water molecules release as well as accelerate the drying process [20]. The low water content of the cocoa beans from the ORF process also corresponds to premium quality or grade AA dry cocoa beans [23]. Although the maximum standard for cocoa bean moisture is 7.5%, the lower moisture content, the lower the potential for moldy cocoa beans, longer dried beans storage, and at the same time facilitates for the further milling process.

Based on the fat content comparison (Table 1), the fermented beans from ORF had a fat content of 25.4% while the WBF was 28.19%. However, these results were still in accordance with the range of fat content value standards. The fat content in cocoa beans is 20-51% depending on the type of cocoa plant [24]. The fat content of cocoa beans can be influenced by several factors, so the fermentation process cannot be the only goal to increase the fat content of cocoa beans. The fat content of cocoa beans can be influenced by genetic factors (clones) of plants, and environmental conditions (seasons) during fruit development [20].

Meanwhile for the pH value, there is no significant difference between WBF and ORF. Both of them have a pH value that tend to be acidic and it is in accordance with recommended standard of fermented beans acidity, with a pH value of 5-5.5 [25]. The fermentation process of cocoa beans that is too long can cause the pH of the cocoa beans to become more acidic. The fermentation process carried out by microbes will break down sugar and citric acid in the pulp into alcohol and organic acids which diffuse into the seeds and induce enzymatic reactions. Lower pH will affect less flavour development [25]. The pH of cocoa beans that are too acidic is caused by the diffusion of acid into the cocoa beans during the fermentation process. The presence of citric acid in the fermentation process makes the cocoa beans pulp environment acidic. The lower pH will affect less flavor development.

Analysis of the biological characteristics of cocoa beans which includes the presence of moldy beans and the presence of biological contamination. Based on the biological test results in Table 1, the presence of mold was found in 1.33% of total cocoa beans from WBF process after being stored for 20 days. This mold appears inside the fermented beans which are entirely on the surface and changes the brown beans into dark green with white patches surrounding them as shown in Figure 5. The moldy that are often found in cocoa beans due to improper handling and processing are *Aspergillus* and *Mucor* sp. [26]. In contrast, the fermented beans from the ORF process were not found any mold or other biological contaminants after 20 days of storage. This due to the processing of cocoa beans is more precise, namely by using a hygienic fermentation container, which is more hygienic, the fermentation process is more controlled, and the faster drying process produces cocoa beans with a low moisture content. In addition, periodic and by-product removal is carried out so that spores and filamentous mold cannot grow in the environment.

Figure 5. Biological contamination in WBF process

Based on the observation of biological contamination (Table 1), the biological contamination from WBF process was found in the form of mold and larvae as shown in Figure 5. Whereas in the ORF process, no biological contamination was found after fermentation even when it was continued up to the drying process. This is due to the glass reactor design intended not only to facilitate visual observation during the fermentation but also able to maintain conditions during fermentation properly without allowing anything from outside the system such as microorganisms that impacting the fermented beans.

3.4. Technical Analysis

3.4.1. Construction

The construction includes the dimensions of the reactor. In the WBF components used are wood with of the length of 19.5 cm, width of 19.5 cm and height of 30 cm. While the ORF is made by integrating ohmic heating technology with a glass chamber and has dimension (l-w-h) of 26-26-30 cm. ORF has a larger capacity than WBF. Thus, in terms of construction, ORF is superior because it can accommodate cocoa beans and produce more fermented cocoa beans. The comparison can be seen in Table 2.

Table 2. The Equipment Construction using WBF and ORF Process

Specifications	WBF	ORF
Dimensions (l-w-h) (cm)	19.5 - 19.5 - 25.5	26 - 26 - 30
Reactor material	Wood	Glass
Temperature control	No	Ohmic heating technology
Capacity (kg)	5	7

The WBF consists of a box with small holes on each side that function as air channels to prevent heat accumulation during the fermentation processIn addition, the box is also equipped with a wooden block 50 cm high as support beneath to make it not contact directly with the ground. Meanwhile, the ohmic reactor design was equipped with DC fan as a cooler when the temperature exceeds the set point. The glass chamber reactor is propped up with a wooden board (40 x 60 cm) which aims to make the chamber and control box in one unit and make it easy to move. In addition, the liquid waste from fermentation can be easily accommodated by the presence of a faucet and processed further into bioherbicides. The bioherbicides is effective for cocoa plants, since it contains acetic acid which is capable of poisoning weeds [27]. While for the WBF process, theresidual liquid from fermented cocoa beans just thrown away and fell to the ground since there is no container equipped. Based on this comparison, the ORF process is more feasible since the waste can be reused into a valuable product.

3.4.2. Operating Method

Although the ORF process uses technology, the operating conditions are still relatively easy, such as using a fermentation process with a wooden box. First, the fermentation using WBF and ORF is conducted by selecting cocoa pods that are ready to be fermented. The characteristics of cocoa pods that are ready to be harvested are changes in the color of the fruit skin from green or red to yellowish or orange in two-thirds of its parts [28]. Furthermore, the fruit is broken down to get the beans.

As previously explained, the operating conditions for the two fermentation processes (WBF and ORF) are not much different, where the cocoa beans are put into the fermentation chamber and waited for the fermentation process to end according to the specified time. The stirring process was also carried out in both methods. In the middle of the fermentation process, stirring is carried out to heat the fermentation heating completely [29].

Factors that influence the success of the fermentation process are temperature [30] and the presence or absence of environmental contamination [31]. The use of ORF can keep the temperature in the reactor under control so that microorganisms can process the substrate optimally, while the use of WBF is not equipped with a temperature controller so it takes a longer time to reach the optimum temperature of fermentation. The use of ORF can also protect cocoa beans from contamination from soil, air, dust, and insects because the fermenter tube is tight and cleaned regularly both pre and post fermentation process. On the other hand, the WBF process is commonly carried out in outdoor or an open place with the aim that the accumulated heat during fermentation can be reduced through the free air outside the room and the fermented liquid waste can fall directly to the ground. The drawbacks of outdoor fermentation conditions are when it rains or in extreme weather, the optimum conditions for a fermentation process will be disrupted and the monitoring process is difficult to do. Whereas in the ORF process, the fermentation process can be carried out indoors or in any room that can be monitored any time. Thus, in terms of operating methods, the use of ORF is more feasible than WBF.

3.4.3. Product Result

The product result from WBF and ORF process as described in Table 1 is different from all parameters. The higher fermented beans produced and has a better quality indicate that the ORF process is feasible to replace WBF process in term of cocoa fermentation process.

3.5. Economic Analysis

The fermentation process of cocoa beans not only affects the formation of color, flavour and other qualities of cocoa products but also has an impact on their selling price. The fermentation process is an important indicator to determine the quality and price of cocoa beans from Indonesia in order to compete in the world market [32]. Unfortunately, 85% of cocoa beans produced in Indonesia skipped the fermentation process which has an impact on the low selling price of cocoa beans in the international market [21]. Therefore, the different method of fermentation is analyzed not only for their technical feasibility but also for their economic feasibility. The results of economic calculations for the WBF and ORF processes carried out in medium industries are shown in Table 3. In this study, the calculation of all economic aspects started from fermentation until dried cocoa beans and based on the actual condition in the medium-sized of cocoa industry. The cocoa pod husk is not included in the economic evaluation even though it can be reused as fertilizer or processed further into other high-value products such as membranes due to its high phenolic content [33].

Table 3. Calculation of Economic Analysis per Month

Description	Units	WBF	ORF
Initial investment cost*	USD	63.60	486.52
Operating costs	USD	15.26	24.93
Received Cost	USD	40.70	126.18
Total revenue (received cost – operating cost)	USD	25.44	101.25
Benefit Cost	USD	25.44	101.25
B/C Ratio	-	1.60	4.06
Payback Period (PP)	Month	1.60	4.80
Net Present Value (NPV)	USD	90.63	687.16
Internal Rate Ratio (IRR)	%	10.70	11.60
$BEP_{Production}$	kg	8.00	11.20
BEP_{Price}	USD	0.95	1.11

Note: *the initial investment costs are carried out only once at the beginning

Based on Table 3, the cost required to make a wooden box equipment is USD 63.60, while for the initial investment to produce an ohmic heating-based reactor is USD 486.52. It is consisting of the cost of raw materials and technology manufacturing services. The operating costs incurred from WBF process are USD 1.91 per batch, while for the ORF process requires USD 2.48. Therefore, the difference in total operational costs in a month is USD 9.67. Although the operating costs for the ORF process are higher than the WBF process, the received costs and benefits cost increased about 3 and 4 times, respectively when using the ORF process.

Based on the medium-sized industry observed, the selling price of dried cocoa beans is USD 2.23/kg, while a bioherbicides as liquid waste from fermentation can be sold for USD 1.27/200 ml. The fermentation process using ORF can produce 2.8 kg of dried cocoa beans and 1.5 liters of bioherbicide with a total revenue of USD 15.77 per batch or USD 204.53 per month. In contrast, the total income from WBF process is only USD 40.70 per month since the dried cocoa beans produced are 2 kg and without selling the liquid waste. Thus, the income obtained after the implementation of the ORF process is higher.

The Benefit Cost Ratio (B/C ratio) of an enterprise will be more profitable or feasible when the ratio between income and expenses is greater or more than 1 [34]. The B/C ratio of both WBF and ORF process is more than 1 which indicates that both fermentation methods are feasible for use in the cocoa processing industry. However, the industry needs a higher benefit-cost than the total costs incurred, indeed. Therefore, the cocoa fermentation assisted by ohmic heating technology can be concluded to be more feasible than using a wooden box.

The payback period of an investment in the enterprise shows the time when the business being carried out recovers its capital costs. Determination of the return-on-investment period is obtained by dividing the total investment by the total revenue per unit of time. Based on equation (6) the medium-sized cocoa industry will get its capital back after 1.6 months by using WBF. Meanwhile, the application of technology (ORF) requires more time to return the initial investment, since the initial investment cost of ohmic reactor is much higher than wooden box. However, with the high demand for premium quality cocoa beans in the cocoa processing industry, the PP value for less than 5 months is still profitable.

The NPV value obtained from calculation (7) shows that the WBF process is considered less economical since it is 7 times lower than using ORF. The NPV value using an ORF which is much larger than the initial investment (USD 486.52) indicates that the use of this reactor is profitable and feasible to implement. Moreover, the IRR value obtained from the calculation (8), shows that the application of ohmic heating reactor for cocoa fermentation is higher than the bank loan interest of 10% [35] as well as higher than the IRR value on the use of wooden box. It can be concluded that the ORF is feasible to be developed.

BEP indicates the minimum number of products and prices in an attempt to find a break-even value. Based on calculations (9) and (10), the breakeven point for getting capital back in terms of the amount of production and prices using ohmic heating technology is greater than that of wooden boxes. However, the $BEP_{production}$ value from ORF (11.2 kg) can be achieved in two fermentation processes or for 6 days. During that period, the WBF process was only able to produce 5 kg of beans and need one fermentation process again to achieve the BEP. This means that within 6 days, ohmic heating technology can reach the breakeven point faster than WBF which takes 12 days to reach the breakeven point. As for the BEP price, the two fermentation methods only require one fermentation process to reach the breakeven point.

4. Conclusions

This research has successfully overcome the drawbacks of the common cocoa bean fermentation method used in Indonesia which uses wooden boxes (WBF). The designed reactor based on ohmic heating technology (ORF) is able to accelerate the fermentation process and produce good-quality cocoa beans. In addition, the quality of fermented cocoa beans through the ORF process is in line with the quality standards for the premium grade in Indonesia and other countries such as Malaysia, Philippines, and globally (ISO). Moreover, the ORF process is also stated as more feasible to be implemented than the WBF process based on an evaluation of its techno-economic aspects. The authors recommend conducting an in-depth investigation and evaluation for scaling up fermentation reactors, where this study just investigated for a small capacity. However, through the findings of this research, it is hoped that the ORF becomes an insight for the cocoa industry, especially on a small scale, to skip the fermentation process and be able to produce good quality cocoa beans in a short time and low cost.

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