Oil palm FFB dry heat sterilization through electromagnetic radiation

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Abstract. Sterilization processes in palm mills demand high energy, intensive water use, and excessive waste. Moreover, the process involves the use of a pressurizing chamber, and hence, extended the time required to complete the batch. Sterilization aims to deactivate the enzyme in the fruits Mesocarp and loosen the fruitlet to ease detachment from the bunch. This study proposes an alternate process with a similar aim and result while reducing the resources required, water in particular. The methods include exposing the oil palm Fresh Fruits Bunch (FFB) with electromagnetic radiation in different power and exposure time. The results showed by presenting the FFB with 180 Watt electromagnetic radiation in 16 minutes, the oil in the Mesocarp extracted as much as 66.71\% of total weight. Furthermore, the properties of extracted oil (DOBI number, carotene content, and FFA level) were superior to the unmodified sterilization process. However, the cost of processing the FFB with electromagnetic radiation remains high, and further study required to economize the cost.

Keywords: CPO, Microwave, mills, water, waste.

1. Introduction
Indonesia has the most extensive oil palm plantation in the world. In 2019, its area reached 16,030,600 [1], and West Sumatra province is the 8th largest. The oil palm fruits milled to extract the edible oil and fat, which then processed into various valuable products, including vegetable oil and biodiesel [2]. However, it produces excessive palm oil mill effluent (POME) wastewater [3]. Oily waste needs to remove to prevent problems that are considered hazardous pollutants, particularly in aquatic environments, because they are highly toxic to marine organisms. Discharging the effluents or by-products on the lands or release to the river may lead to pollution and might deteriorate the surrounding environment.

In oil palm processing, sterilization is the primary stage to deactivate the enzyme in the fruits Mesocarp. The process promotes separation of the fruit from its stalks, reduces the water content of the fruits’ Mesocarp, separating the fruits’ kernel from the shell, and reducing the fibre integrity to ease oil extraction [4]—the process demand high energy, intensive water use, and excessive waste. Moreover, the process involves exposing the oil palm fruits with high-pressure hot-saturated-steam in the pressurize-chamber. Hence, extended time is required to complete the batch [5]. This moist heat sterilization produces a large quantity of wastewater, known as palm oil mill effluent (POME) [6]. The POME requires high costs treatments to conform to the standards for disposal into the environment. Therefore, it is necessary to explore the dry heat sterilization process to reduce water use and waste in oil palm processing.
Dry heat sterilization is the earliest form of sterilization [7]. It works by exposing hot air to the object [8]. However, this sterilization technique requires longer exposure time and higher temperatures than moist heat sterilization. Thus, it is not economical for processing oil palm fruits. On the other hand, heating and cooking food or agricultural products using a microwave is a common practice. The technique exposes electromagnetic radiation in the microwave frequency, or microwaved, range to the product. It induces polar molecules in it to rotate and produce thermal energy in a process known as dielectric heating [9]. The process heat food quickly and efficiently because excitation is relatively uniform in the outer 25–38 mm of a homogeneous, high water content food item [9]. Furthermore, the technique can use for sterilization processes since the radiation produced by microwaves proven to be effective in removing and deactivating microorganisms and biomolecular molecules such as enzymes [10].

Therefore, in this study, the possibility of using microwave sterilization for oil palm processing was explored. The influence of microwave radiation intensity, as well as time exposure, were observed. This study's result will open the pathway for revolutionizing Indonesia's oil palm industry and throughout the entire producer countries. Besides, the successful results may reduce the cost and waste effluent of oil palm processing production.

2. Materials and Methods
This research conducted in July-August 2019. The samples were 60 oil palm (Elaeis guineensis Jacq.) FFB of Tenera variety. The FFB harvested at fully ripe [11] from 7 to 14 years’ plants [12]. Samples obtained from the different plantations (0°15'50.2"S and 99°59'06.7"E; 0°09'04.4"S 100°01'31.8"E; 0°46'11.5"S 100°16'36.3"E; and 0°41'00.8"S 101°01'18.2"E). Each FFB then weighed [13] and chopped into two parts. Each part then reweighed.

The first half directly sterilized using the standard technique (moist heat sterilization) [14]. The rest then immediately microwaved, according to Table 1. The differences of power and time exposure for microwaving the FFB aimed to study the influence of the sterilization performance and the oil quality extracted from the FFBs mesocarps. The palm oil can deteriorate due to heat exposure [15].

| No | Method | Exposure Time (min) | Radiation Power (Watt) |
|----|--------|---------------------|------------------------|
| 1  | A      | 4                   | 720                    |
| 2  | B      | 6                   | 540                    |
| 3  | C      | 12                  | 360                    |
| 4  | D      | 16                  | 180                    |

The Microwave used in this study was a built-in solo microwave (Samsung, NQ50K3130BS, Korea) with a maximum power output of 800 watts [16]. The electromagnetic radiation emitted by a magnetron (OM75P-21) at a frequency of 2450 MHz. During microwave sterilization, the FFBs temperature were maintained below 100 °C. Whereas steam sterilization process pressurized the bunches of 15-45 psi for 90 min at a temperature of more than 100 °C [17].

The FFB then weighed, the fruits were separated manually from the bunch to prevent damage or injuries to the mesocarp tissue. To obtain the mesocarp, fruits were separated from its kernel manually, then the mesocarp were weighed. The quality attributes in this research (Moisture content, Hardness, Oil Content, FFA, DOBI, and carotene) determined based on the standard method.

Measurement of moisture content for Mesocarp, shell, core, and oil palm bunches with the drying process using an oven. The Mesocarp, shell, core, and bunch dried for 12 hours at temperature 105-110 °C until constant. The moisture content (%) calculated using Eq. (1):

\[
\text{Moisture Content (\%)} = \frac{b-c}{b-a} \times 100\%
\]  

(1)
where a is empty thimble weight; b is thimble weight and sample before drying, and c is thimble weight and sample after drying.

The hardness of FFB and detached fruitlets measured after treatment. Hardness is measured using a force gauge. The hardness calculated using Eq. (2):

\[ P = \frac{F}{A} \]  

(2)

where P is Pressure (N / m²); F is Force (N), and A is Area (A = \pi d ^ 2) (m²)

The oil content of oil palm FFB was determined using the Soxhlet method on a wet weight basis. The FFB samples weighed and dried to remove excess water. After that, Soxhlet extractor used to extract the mesocarp oil from the FFB samples with hexane as the chemical solvent. The residue of fiber and oil solution in the thimble was dehydrated and cooled in the desiccator. The mesocarp oil content (% oil content) of oil palm FFB calculated using Eq. (3):

\[ \text{% Oil Content} = \frac{W_1 - W_2}{W_3} \times 100 \]  

(3)

where W₁ is thimble and extra weight (g), W₂ is empty thimble weight (g), and W₃ is mesocarp weight (g).

The FFA in the oil measured by the titration method. The percentage of FFA in CPO calculated as palmitic acid and interpreted as the mass of NaOH (in milligrams) required to counteract the acid. The percentage of FFA (as palmitic acid) expressed as:

\[ \text{FFA} = \frac{V \times 25.6 \times 1.929}{M} \]  

(4)

where V is the volume of NaOH (ml); 25.6 is the constant based on the molar mass of palmitic acid, and M is sample mass (g).

Deterioration of bleach ability index (DOBI) analysed using spectrophotometric methods. The DOBI calculated using Eq. (5):

\[ \text{DOBI} = \frac{\text{Abs at 446 nm}}{\text{Abs at 269 nm}} \]  

(5)

Carotene was measured using the spectrophotometric method. The carotene calculated using Eq. (6):

\[ \text{Caroten}e = \frac{25 \times 383 \times \text{Abs}}{100 \times M} \]  

(6)

Where Abs is Absorbance of the sample; M is sample mass (g)

Economic analysis in this study to determine the fixed and variable costs of Microwave. Fixed costs are depreciation and capital interest costs, while variable costs come from maintenance costs, operator costs, and electricity costs.

The Depreciation Costs calculated using Eq. (7):

\[ D = \frac{(P-S)}{N} \]  

(7)

Where D is Depreciation (IDR / year); P is Asset price (IDR); S is Salvage Value (IDR), and N is Useful life of the asset (years).

The Cost of Capital Interest calculated using Eq. (8):

\[ I = \frac{R \times (P+S)}{2} \]  

(8)

Where I is the Capital Interest (IDR / year); P is Asset price (IDR); S is Salvage Value (IDR); R is Interest Rate (6%)

The Fixed costs (FC) calculated using Eq. (9):

\[ \text{FC} = D + I \]  

(9)

Where FC is Fixed costs (IDR/year); D is Depreciation (IDR/year); I is Interest Rate (IDR/year)

Variable costs are calculated based on maintenance costs and operator costs. The maintenance costs calculated using Eq. (10):

\[ \text{MC} = \frac{2\% \times (P-S)}{100 \text{ jam}} \]  

(10)

Where P is Asset price (IDR); and S is Salvage Value of Microwave (IDR)

The Operator costs calculated using Eq. (11):

\[ \text{OC} = \frac{\text{Wop}}{\text{Wot}} \]  

(11)

Where OC is Operator Cost (IDR / hour); Wop is Labour Wage (IDR / day); and Wot is Working Hours per Day (hour/day)
The electricity costs calculated using Eq. (12):

\[ EC = P \times pr \]  

(12)

Where EC is Electricity costs ( IDR/ Hour); P is Power used (kW); and pr is Price per kW ( IDR / kWh).

The variable costs calculated using Eq. (13):

\[ VC = MC + OC + EC \]  

(13)

Where VC is Variable costs ( IDR/hour); MC is Maintenance Costs ( IDR/hour); OC is Operator Costs ( IDR/hour); WL is Electricity Costs ( IDR/hour).

The Electric Energy calculated using Eq. (14):

\[ El = \frac{(P \times T \times \eta)}{Tot} \]  

(14)

Where El is Electrical energy ( MJ / kg); P is Asset power (KW); T is Time of asset usage (hours); and I] is The technical efficiency of the tool; Tot is Total CPO production (kg).

The Gas Cost calculated using Eq. (15):

\[ \text{Gas cost} = (W2 - W1) \times \left(\frac{\text{gas price}}{\text{kg}}\right) \]  

(15)

Where W1 is Initial Tube Weight; and W2 = Tube + Gas Weight.

The Steam Energy calculated using Eq. (16):

\[ SE = (\text{Mu} \times hs \times T) \]  

(16)

Where SE is Steam Energy ( MJ / kg); Mu is Steam rate (kg/hour); hs is Steam enthalpy (kJ / kg) from the Superheated Table; T is Working Hours (hours); J is Total CPO Production (kg/day).

The Required heat calculated using Eq. (17):

\[ Q = m \times c \times \Delta T + Qm \]  

(17)

Where m is Water Mass (kg); c is 4200 ( J / kg K); \( \Delta \) is Temperature Change (° K); Q is Number of Calories Used (joules); Qm is m x hs (kJ).

3. Results and Discussion

In oil palm processing, sterilization is the main step to deactivate the Mesocarp enzyme in the fruit. This process promotes the separation of the fruit from the stem, reduces the fruit mesocarp moisture content, separates the fruit core from the shell, and reduces fibre integrity to facilitate oil extraction [4]. It is common practice to use microwaves for agricultural cooking and heating. This technique exposes electromagnetic radiation in microwave frequencies, or microwaves, to the product. This induces the polar molecules inside to rotate and generates heat energy in a process known as dielectric heating [9]. Energy is essential in treatment. Factors that affect energy is time and high voltage. The total microwave energy is in Table 2.

| Table 2. Total energy microwave |
|--------------------------------|
| **Microwave** | A  | B  | C  | D  |
| Power (W)      | 720 | 540 | 360 | 180 |
| Time (hours)   | 0.07 | 0.10 | 0.20 | 0.27 |
| Total Energy (kWh) | 0.05 | 0.05 | 0.07 | 0.05 |

* A: 720 W time 4 minutes, B: 540 W time 6 minutes, C: 360 W time 12 minutes, D: 180 W time 16,
P1: Sterilization 1, P2: Sterilization 2

Based on Table 2, the highest total energy is in treatment C. The total energy is 0.07 kWh, with 360 W for 12 minutes. The smallest total energy is in treatment D, which is 0.03 kWh. The longer the heating time causes the lower total energy.

The hardness measured by calculating the hardness value of detached fruitlet after microwave treatment and sterilization. The hardness of the detached fruitlet in Figure 1.
The value of the detached fruitlet in the microwave treatment is 13 N/cm². The highest value of detached fruitlet hardness is treatment B at a power of 720 W for 4 minutes. The lowest detached fruitlet hardness is treatment C at 360 W. Based on Figure 1b, the highest value of fruit hardness is in treatment D, which is 10,947 N/cm² at 180 W for 16 minutes. The lowest fruit hardness value was in treatment B, which was 10,470 N/cm².

Determination of moisture content aims to determine the percentage of water in the sample in the microwave treatment and sterilization. The moisture content of Mesocarp is in Figure 2. Based on Figure 2a, the value of Mesocarp moisture content is lower when using a microwave. The average moisture content value using the microwave method is 26-29%, whereas, with the sterilization method, the average moisture content value is 26-27%. The value of moisture content by the microwave method, which is close to the value of the sterilization method, is treatment D, with a value of 26,002%.

The difference in the value of moisture content in the treatment is due to the longer heating time. The value of moisture content decreases if the heating time increases. Based on Figure 2b, the value of the moisture content is lower by the microwave method. The microwave method's average moisture content value is 60-70%, whereas, with the sterilization method, the average moisture content value is 71-72%. The best value of moisture content by microwave treatment is treatment B, with a value of 70.122%. Based on Figure 2c, the value of the moisture content is lower when using a microwave. The average moisture content value of four treatments is 20-26%, whereas, in the sterilization method, the average moisture content value is 34-35%. Value of shell moisture content is 15-20% [18]. The average value of shell moisture content by the microwave method did not differ significantly from the literature.

In contrast, the value of moisture content for sterilization was higher than the literature value. The duration of sterilization causes a high value of moisture content. The best average moisture content is treatment B, and the moisture content value is 20.917% with a heating time of 6 minutes, and the power is 540 W.

Based on Figure 2d, the palm kernel's average moisture content with the microwave method for four treatments is 20-23%, while with the sterilization method, the average moisture content is 20-21%. The value of palm kernel moisture content is 15-25% depending on processing [19]. Based on the study results, the average value obtained was not significantly different from the literature. The value of moisture content, which is close to the sterilization value, is treatment D with an average value of 21.291; this is because of the influence of the power used.
Furthermore, the quality parameters of FFB were observed, which consisted of DOBI, carotene, FFA, and oil content (Figure 3). DOBI is a comparison of adsorbent absorption rates with free fatty acids. DOBI is an index of the degree of paleness in crude palm oil. Oil purification aims to eliminate the colour (bleaching) that is less favoured in oil, so DOBI is very important in refining palm oil. Measurement of DOBI values obtained from the absorption ratio of UV-Vis spectrophotometer at wavelengths of 446 nm and 269 nm [20].

The highest average DOBI value by the microwave method is D treatment with a DOBI value of 3.561 nm, while in the method of sterilization, the highest DOBI value is P2 treatment with a value of 3.781 nm. According to the Indonesian National Standard, the best DOBI value is around 3.23 nm. Based on the two methods applied, high-quality DOBI values in the sterilization method. The value of DOBI for microwave treatment is lower because of the effect of different temperatures in each treatment by the microwave method. Higher temperatures cause DOBI quality to decrease.

Carotene is an orange photosynthetic pigment that is important for photosynthesis. The carotene content in red palm oil is 600 to 1000 ppm, the carotenoids in palm oil consist of α-carotene ± 36.2%, β-carotene ± 54.4%, τ-carotene ± 3.3%, lycopene ± 3.8% %, and santophils ± 2.2% [19]. Carotene is one of the determinants of oil quality. Carotene is a source of vitamins A and E in Crude Palm Oil (CPO). Carotene values were measured using a spectrophotometer with absorbance values at wavelengths of 446 nm and 269 nm.

The highest average carotene value using the microwave method is in the D treatment with a value of 683.0985 ppm, while in the sterilization method, the highest value is in the P2 treatment with a value of 744.998 ppm. Based on Indonesian National Standard carotene, BOB value are (500-700 ppm); this value is in treatment D with an average value of 683,099 ppm. Low carotene value causes the oil quality is low where the color is pale. The higher DOBI and β-carotene values cause the quality value to increase so that CPO's price is increase [20].
Free Fatty Acid (FFA) is the main factor in determining the damage of CPO quality. The quality standard for CPO free fatty acid levels is 5%. The average value of free fatty acids is 0.19-0.29%. The highest value is in treatment A with a power of 720 W for 4 minutes using a microwave. Based on Indonesian National Standard 2006, palm oil-free fatty acids are smaller than 5%. High free fatty acids cause a decrease in yield to the processing of CPO yield. One process that can reduce free fatty acid levels in CPO is the neutralization process. The results of the average value obtained for the value of free fatty acids by the microwave method and sterilization by predetermined standards are below 5%.

Crude Palm Oil produced from the extraction or pressing process of palm oil mesocarp. Determination of oil content in this study using the Soxhlet method. The average value of the oil content of the microwave method has different values. In treatment A, the value of oil content was 50.986%, treatment C was 54.183%, treatment D was 67.580%, and treatment D was 66.714%. The difference in oil content between treatments is due to the effect of power and duration. Increased power and less time produce low oil content.

Economic analysis was carried out to compare the effectiveness and efficiency of sterilization techniques on FFB [21]. Economic analysis for microwave method and sterilization in this study is in Figure 4.

Based on Figure 4, the costs required in the sterilization process using a microwave are lower than the standard sterilizers that are generally used. The standard sterilization technique that is commonly used requires longer exposure time and higher temperatures than moist heat sterilization. Thus, it is not economical for processing palm oil fruits. Meanwhile, if using a microwave, the process heat quickly and efficiently because excitation is relatively uniform in the outer 25–38 mm [9]. Furthermore, the technique can use for sterilization processes since the radiation produced by microwaves proven to be effective in removing and deactivating microorganisms and biomolecular molecules [22] such as enzymes [10].
4. Conclusions
In this study, the possibility of using microwave sterilization for oil palm processing was explored. Based on the research, the microwave sterilization process has superior performance in relation to time as compared to the current sterilization process. Microwave treatment with a 180 Watt power in 16 minutes is the best treatment in producing the quality of FFB oil as measured in the DOBI value, FFA, and carotene. Based on research, it is known that the microwave method is more effective than the sterilization method.

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References
[1] BPS. 2019. Plantation Area by Province and Type of Plant. Central Bureau of Statistics. Indonesia.
[2] Cherie D, Rini R, and Makky M 2020 Optical properties of oil palm Fresh Fruits Bunch (FFB) for optimum harvest-window prediction Journal of Physics: Conf. Series 1469(012105) pp. 1-8 doi:10.1088/1742-6596/1469/1/012105
[3] Hesam K, S Chelliapan, MFM Din, S Rezania, T Khademi and A Kumar 2018 Palm Oil Mill Effluent as an Environmental Pollutant. Intechopen. DOI: 10.5772/intechopen.75811
[4] Makky M, D Yanti, I Berd. 2018. Development of Aerial Online Intelligent Plant Monitoring System for Oil Palm (Elaeis guineensis Jacq.) Performance to External Stimuli. International Journal on Advanced Science, Engineering and Information Technology. 8(2): 579-587
[5] Junaidah, M. J. 2015. Optimisation of Sterilisation Proces for Oil Palm Fresh Fruit Bunch at Different Ripeness, IFRJ 22(1): 275-282.
[6] Singh RP, Ibrahim MH, Esa N, Iliyana MS 2010 Composting of waste from palm oil mill: A sustainable waste management practice. Reviews in Environmental Science and Bio/Technology. 9(4):331-344
[7] Baveja CP 2019 Textbook of Microbiology 6th Ed. APC-India. ISBN 81-7855-266-3
[8] Ananthanarayan and Panikar 2005 Textbook of Microbiology 7th Ed. Orient Longman Private Limited – India. ISBN 81-250-2808-0
[9] Chaplin M 2012 Water and Microwaves Water Structure and Science. London South Bank University
[10] Makky M, P Soni, VM Salokhe. 2014. Automatic non-destructive quality inspection system for oil palm fruits. International Agrophysics 28(3):319–329
[11] Cherie D, Rini R, and Makky M 2019 Determination of the optimum harvest window and quality attributes of oil palm fresh fruit bunch using non-destructive shortwave infrared spectroscopy AIP Conference Proceedings 2155, 020034 https://doi.org/10.1063/1.5125538
[12] Makky M 2016 Trend in non-destructive quality inspections for oil palm fresh fruits bunch in Indonesia International Food Research Journal 23(Suppl): S81-S90
[13] Cherie D, Herodian S, Ahmad U, Mandang T, and Makky M 2015 Optical Characteristics of Oil Palm Fresh Fruits Bunch (FFB) Under Three Spectrum Regions Influence for Harvest Decision International Journal on Advanced Science, Engineering and Information Technology 5(3) pp. 255-263, DOI:10.18517/ijaseit.5.3.534
[14] Makky M, and Soni P 2013 Development of an automatic grading machine for oil palm fresh fruits bunches (FFBs) based on machine vision Computers and electronics in agriculture 93, pp. 129-139
[15] Makky M, and Soni P 2014 In situ quality assessment of intact oil palm fresh fruit bunches using rapid portable non-contact and non-destructive approach Journal of food engineering 120, 248-259
[16] Samsung 2016 Microwave Oven User manual NQ50K. 3130 Samsung
[17] Sivasothy K 2000 Palm oil milling technology Advances in Palm Oil research 1, pp. 745-775
[18] Daily Lab. 2019. Quality Standards for CPO Processing. Jambi..Company X
[19] Naibaho, P. 1996. Palm Oil Processing Technology. Medan: Oil Palm Research Center.
[20] Afriani, Mutia. 2009. Relationship Analysis of DOBI (Deteration OF Bleachibility Index) and β-carotene in CPO (Crude Palm Oil) Using UV-Visible Spectrophotometry. Medan: University of North Sumatra.
[21] Makky M. 2016. Multi-modal Bio-metrics Evaluation for Non-destructive Age States Determination of Tomato Plants (Solanum lycopersicum). International Journal on Advanced Science, Engineering and Information Technology 6(3):345-348
[22] Paschalidis, K.; Tsaniklidis, G.; Wang, B.-Q.; Delis, C.; Trantas, E.; Loulakakis, K.; Makky, M.; Sarris, P.F.; Ververidis, F.; Liu, J.-H. The Interplay among Polyamines and Nitrogen in Plant Stress Responses. Plants 2019, 8, 315.