The Effect Moisture Residue in Oil Palm Fruits with Microwave Technique: Quantifying the Significant Factor of Residual Moisture as the Process Parameter for Commercial Sterilization

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Abstract—**Drying sterilization (hot air and microwave heating) in oil palm mill is one of the alternative solutions. On the one hand, most of the previous studies are mainly focus on the power and exposure time in order to find the optimal condition for commercial-scale, but those conditions are possibly impractical when the batch size or physical properties of oil palm fruits change. Since the power and time represent the energy that put into the system during sterilization, the removing weight of oil palm fruits as equivalent to moisture content also directly relates to the amount of energy consumption. Therefore, in the present study, a controlling moisture residue was examined by the design of the experiment. The given result showed that 15% of moisture residue could be proper to control to achieve the standard requirements. The 15% of residual moisture was proved again by varying the treatment pathways of batch size and power of heating, the statistical analysis assured that there was no significant difference (*$P \geq 0.05$*) from the effect of different pathways when the oil palm fruits were treated at the same level and giving the positive results. All in all, the suitable value of moisture residue can be applied as the process parameter of drying sterilization oil palm fruits with a promising result of both physical properties and crude palm oil qualities.**

Index Terms—**residual moisture content in oil palm fruits, moisture controlling in oil palm fruits**

I. Introduction

Since the Sterilization process in palm oil production, high-pressure stream in the conventional palm oil mills and some with non-steamed sterilization drying in the small plant is the crucial step in order to produce the important attribute of palm oil qualities following the trading requirements, the selection method of sterilization and process management in the palm oil mill might affect the extracted crude palm oil. Generally, oil palm fruits bunches are subjected to the sterilization process for two main purposes, i) to detach the oil palm fruits from the bunches, and ii) to inactivate the lipolysis enzyme that affects to the increment of Free Fatty Acid (FFA) in crude palm oil [1]. In addition, Deterioration of Bleachability Index (DOBI) of crude palm oil, one of the important indicators to measure the oxidation level, rancidity and ease of refining process before using in food manufacturing could also be affected by the sterilization process [2], [3].

However, most oil palm mills have utilized steam as a heat source in sterilization process which conducts saturated steam pressure around 40 psi for 90 minutes [4]-[6] with the use of sterilization process, the oil palm mills have to cope with a large amount of waste water as Palm Oil Mill Effluent (POME) with a high treatment cost [7]. Therefore, in the past couple of decades, several attempts were performed to replace and develop the conventional oil palm fruits sterilization process, for instance, continuous sterilization process [5], dry heating together with solvent extraction [8], radio-frequency heating palm fruits [9]. Among the alternative solutions, microwave sterilization of oil palm fruits has been extensively conducted due to its beneficial advantages such as faster heating with high energy efficiency, volumetric heating, and shorter heating time. Moreover, heating with the microwave also has a valuable impact on both physical properties and chemical properties, natural antioxidants, and oxidative stability [10]. Kanjanapongkul K. [11] studied the use of ohmic combined with microwave heating for pre-treating oil palm fruits. The effects of the pre-treatment method on FFA, Peroxide (PV), beta-carotene concentration, and energy consumption were evaluated. The results showed that the FFA content using microwave was 1.70% w/w and remained below the critical limit even after 8 weeks of storage, and the yield was 44.5% w/w. An exploratory studied by Chow and Ma [12] reveals that microwave heating together with solvent extraction shows a possibility to replace the conventional sterilization process. The study also shows that microwave drying is suitable for detaching oil palm fruits from bunches and spikelets. Furthermore, by using three minutes of time exposure is recommended to achieve the general requirements such as un-decomposed kernel, inactivating the enzymatic lipolysis which causes of Free

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Fatty Acid (FFA) increment. Similarly, the investigation by Cheng *et al*. [7] states that the physical appearances of dried palm fruits, vitamin E, and carotenes in crude palm oil have been affected by the exposure duration. They recommended that heating time of 3 minutes will possibly yield the Oil Extraction Rate (OER) for more 20%, meanwhile, sterilization for 2 minutes will maintain a high concentration of vitamin E and carotene. In addition, Umudee *et al*. [6] also recommends that the suitable condition of microwave sterilization should be controlled the temperature on mesocarp ranging from 50°C to 80°C in order to guarantee the general qualities of crude palm oil.

Besides, controlling a drying condition of oil palm fruits to achieve a good quality in terms of FFA, DOBI, and OER is very crucial. Rahman and Al-Farsi [13] revealed that drying treatment with different exposure time affects the measocarp's texture, such as hardness and resilience, which resulted in the efficiency of dehusked measocarp from kernel (nut separation) and quantity of palm oil yield in the extraction process. Therefore, inefficient heat penetration of a heat source to penetrate inside a stack of oil palm fruits would lead to the problem of non-uniformity of dried palm fruits [14]. Another problem that always happens in the sterilization process is that it is difficult to control an optimal condition due to the mixed condition of the batch, which has a diversity condition of palm fruits such as ripeness, bruise or maturity [15].

Based on the previous studies, although most exploratory experiments by researchers have attempted to replace conventional sterilization process by microwave technology, which showed a great potential to be used for sterilizing oil palm fruits, they have mainly focused on the two parameters which are the power, and the exposure time. These factors are somewhat specific and impractical since the proposed condition of suitable exposure time is too short for the commercial scale [16]. For this reason, measuring moisture content of oil palm fruits during the oil palm sterilization is more during sterilization process of oil palm fruits because its value is commonly used in food processing and related to the alteration of sterilization and qualities.

Therefore, in this study a novel microwave sterilization technique to control dehydration of moisture content in oil palm fruits is proposed and used as the main controlling parameter instead of using the power and time. The indicator of suitable moisture residue, after sterilization oil palm fruits, can be determined as one of the important process parameters which will be useful in general microwave sterilization of oil palm fruits. To prove this concept, in the first part of this study, three levels of moisture residue in oil palm fruits at 5%, 15%, and 25% were controlled. The most favorable moisture residue was selected based on measuring of 5 categories: FFA, DOBI, kernel condition, energy consumption, and Oil Extraction Rate (OER). Next, in the second part, the representative of the most favorable moisture residue was examined again in the different pathways, namely, oil palm fruits were treated by varying the power (800Watts & 400 Watts), and mass of oil palm fruits (100g & 300g). The total combination effect with 5 replications for each treatment was 20 treatments. These treatments will prove that the residual moisture in oil palm fruits at the target will ensure that whether or not its level could be applied practically as the significant parameter for microwave sterilization process.

II. Materials and Methods

A. Processing of Fresh Palm Fruits Collection: Sampling Method

A ripped fresh fruits bunch (Tenera) was obtained from Saraburi province, Thailand. Next, unburied oil palm fruits were detached from basil, equatorial, and apical zone. Since the majority of the diversities of oil palm fruits, for instance, weight, shape or physical appearances in this study were concerned, the sampling method of picking oil palm fruits in this study was controlled carefully by dividing 5 sample groups which consisting of representative group, Treatment A, B, C and D. About the oil palm fruits in the Representative group, all fruitlets were only conducted for measuring the initial moisture content by a gravimetric method with oven drying at 105°C for 24 hours and reweighing the total weight until the weight did not change as a percentage following the equation (1). After that, the initial moisture content from this group will be set as the initial value for all treatments in order to estimate the proportion of the mass of water and solid individually for controlling the moisture levels to the target of 5%, 15%, and 25% respectively.

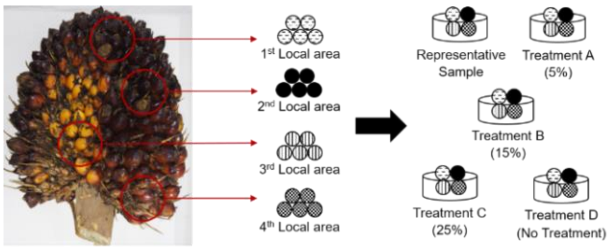

Figure 1. Sampling procedure for preparing palm fruits in the experiment.

The sampling method in this study has been done by specifically picking up five oil palm fruits from local area and placing one in each basket (1st collection), namely, a representative sample, treatment A, B, C, and D as can be seen in Fig. 1. Then, repeat the same procedure by determining the other area (2nd collection) and putting down the palm fruits into each basket until the overall weight of each palm fruits in treatment basket is close to the targeted, which is approximately 200 grams/basket. Using this methodology, it can be ensured that all the sample basket for different treatments would be fairly selected without bias.

B. Determination of Moisture Content: Initial Moisture Content

The initial moisture content was determined using the representative group. All fruitlets in the representative was placed in a hot air oven at 105°C following gravitation method until its weight was no longer changed. A percentage of initial moisture content in term of wet basis ($\%MC_{initial}$), can expressed as:

$$\%MC_{initial} = \left(\frac{W_{initial}-W_{final}}{W_{initial}}\right) \cdot 100 \quad (1)$$

C. Dehydration Rate of Moisture Control: Microwave Heating

The Toshiba ER-G23SC, 800 W, and 2450 MHz was used for all microwave heating treatments. A chamber of a microwave was modified by adding an AND-GF1000 weighing scale on the top side of the oven and hanging an oil palm fruit container using polypropylene rope at the center point of the oven as depicted in Fig. 2.

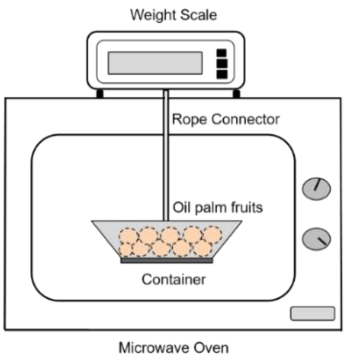

Figure 2. Schematic of experimental setup for dehydrating palm fruits.

The procedure of dehydration control on residual moisture palm fruits in treatments A, B, and C with target moisture level at 5%, 15% and 25% is firstly determined the weight of solid; (W_{solid}) (dry-basis) in each treatment which can be calculated as:

$$W_{solid} = \left(\frac{100-MC_{initial}}{100}\right) \cdot W_{initial} \quad (2)$$

where $MC_{initial}$ is the initial moisture that obtained from (1) and $W_{initial}$ is the initial weight of oil palm fruits in the treatments A, B, and treatment C.

The targeted moisture control (MC_{target}) at X% is determined from the targeted weight (W_{target}). After palm fruits are loaded in the container inside a microwave, they will be heated and carefully measured and simultaneously by the scale according to the targeted moisture control, calculating by the following equation:

$$W_{target} = \left(\frac{100 \cdot W_{solid}}{100-MC_{target}}\right) \quad (3)$$

D. Oil Palm Extraction Rate (OER): Automatic Palm Oil Presser

In Fig. 3, after finishing the process of microwave sterilization, dried palm fruits (c) were instantaneously separated kernel (nut), and mesocarp. Only dried pulp (b) from each conditional treatment was then squeezed to be crude palm oil without any pre-heat by automatic palm oil presser which fixed a force limitation in 20.3 N by electrical controller (a). The percentage of OER was calculated by:

$$OER = \left(\frac{W_{CPO}}{W_{dried\ pulp}}\right) \cdot 100 \quad (4)$$

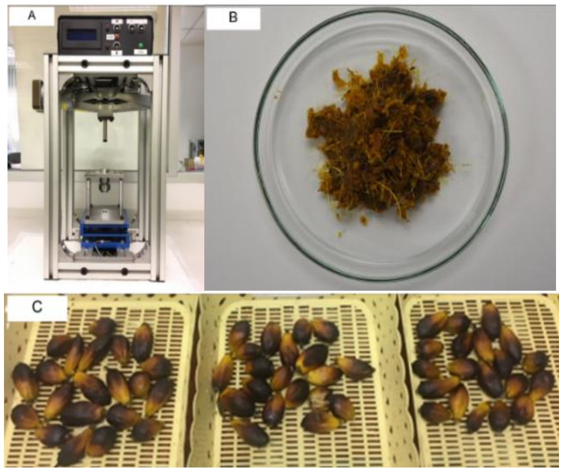

Figure 3. The process of oil palm extraction in the experiment. (A) automatic palm oil presser (B) dried pulp, and (C) dried palm fruits after treatment.

E. Influence of Palm Fruit Storage Time on Free Fatty Acid Content of Palm Oil

Physical appearances of palm fruits in each pile were observed on 0^{th} and 15^{th} day. Their FFA contents on 0^{th}, 5^{th}, 10^{th}, and 15^{th} day were determined.

F. Free Fatty Acid Content Determination

The FFA contents were determined from 5-7 fruits sampled from each of 5 piles on 0^{th}, 5^{th}, 10^{th}, and 15^{th} day. On the measuring day, palm oil was extracted from the sampled fruits of each conditional treatment for approximately 1.0g ($\pm$0.05g), which were then kept in the glass tube individually, and finally FFA content was measured by using automatic titrator TitroLine 7000 (SI Analytics, USA) 3 times for getting the average data. The solvent and titrants were isopropanol and potassium hydroxide (KOH), respectively, in each measurement process.

III. Results and Discussion

A. Part A: Investigation of the Most Suitable Condition of Controlling Moisture Residue under Microwave Sterilization

The experiment in part I shows how the moisture residue in a treated group has been done by varying the targeted moisture at 5%, 15%, and 25% respectively. Three replications of the test were performed for every treatment in order to find the most suitable condition of moisture revel, regarding palm oil qualities, physical appearances, energy consumption, and oil extraction rate.

According to the given data in Table I, the initial weight of palm fruits in each treatment was measured in order to estimate the portion weight of moisture and targeted weight as representing the targeted moisture following equation (1)-(3).

The actual final palm fruits weight represented the actual weight that the examiner had manipulated in the actual performance, because during microwave heating, the existing water content that was released from the sample was not constant and made the value of target moisture slightly in error. However, the arrival of final moisture content could be controlled nearly of the target as 6.57% in Tr-A, 16.64% in Tr-B, and 26.02% in Tr-C respectively.

Once all treatment had been done, those dried palm fruits, nut, and dried pulp, was immediately separated for palm oil extraction. Both the Tr-A and Tr-B were the group which used longer time than others, it can be seen that oil palm fruits upon exposure time show a considerable trend with oil extraction rate as the higher exposure time, the more obtain yield of oil extraction rate. Similarly, the given result of Hadi *et al.* [8] that they varied the heating time of oil palm fruits for 1-5 minutes.

Consideration of the comparison of the results of palm oil qualities in the same Table I show that, even though the initial value of FFA after extraction in the first day from treated group Tr-A, -B, -C & untreated group (Tr-D) show a good quality with low level, but after storage of CPO for 14-days, only FFA in Tr-D plunged remarkably in contrast with the treated group that remained positively within the requirements. Based on these results, even though the FFA from the treatment group can ensure that FFA level follows the trading standard as it does not exceed 5% [16], the CPO from Tr-C still shows an negative increment during preservation and it might not be allowed to be preserved longer than 14-days. For this reason, only Tr-A and Tr-B are recommended as the lipase activity has been completely halted.

The value of DOBI represents the essential amount of chemical (bleaching earth) that is used for the refining of crude palm oil in food manufacture. Its quality is classified as poor (1.78–2.30), fair (2.31–2.92), good (2.93–3.24) and premium grad over 3.24 [2]. Based on the obtained results in this study, DOBI from Tr-D was always the least compared with other treated groups. Its value was less than double in comparison with Tr-A and Tr-B. Meanwhile, the statistical analysis shows that DOBI after storage for 14 days has a significant difference between the treated group and the untreated group at $P \leq 0.05$. The range of treated group ranged from 5.30–5.96 and untreated group was 2.63. The main reason why total DOBI from an untreated group is substantially lower than the treated group can be described by the total number of carotene and secondary oxidation. The given quantity of absorbance from the CPO in each treatment is illustrated in Fig. 4, the absorbance at 446nm represents the content of total carotene, and 269nm represents secondary oxidation [17]. The initial value of total carotene from each group varied naturally without significant difference (at 95% probability) from random selection, but the main significant factor that makes dichotomy is that secondary oxidation might activate the deterioration of the quality of CPO after storage as can be observed the quantity of absorbance from Tr-D was greater than other treated group. Namely, without appropriate sterilization, palm fruits (Tr-D) showed a higher possibility of oxidation than the treated group. Consequently, the higher dehydration moisture equals, higher inhibit of the rate of oxidation that makes DOBI acceptable for trading requirements.

The physical appearances of mesocarp and kernel are depicted in Table II under microwave sterilization with the same power, as mentioned before a greasy fiber on mesocarp was observed to release oil when it was exposed longer and making its texture to be slightly hardened. Similarly, the kernel color of Tr-B and Tr-C remained in a good appearance compared with the untreated group.

On the contrary, Tr-A which had an over dehydrated moisture content in the low level, its kernel was slightly burnt and became brown. This phenomenon is consistent with the experiment by Chow and Ma and Cheng *et al.* [7], [12] as longer exposure time, the kernel trends to be undergo an unusual condition for the further process of extracting oil from the kernel. However, the time of exposure in this test in Tr-B and Tr-C was totally different from the previous study as batch size was increased (weight), about 25 minutes and 15 minutes was measured for Tr-B and Tr-C respectively compared to the recommendation of previous study by longer than nearly 10 times. Therefore, in the practical process, instead of determining the suitable time, moisture control can be applied as one significant factor that is available to control, providing that oil palm fruits are properly dehydrated to the acceptance level.

TABLE I. THE PARAMETERS AND RESULTS OF DEHYDRATE MOISTURE CONTROL IN EACH TREATMENT

Treatment	**A** **5%wb**	**B** **15%wb**	**C** **25%wb**	**D** **No treatment**
Initial palm fruits weight [g]	204.68	207.16	206.39	195.98
Weight of moisture [g]	59.61	60.64	60.41	57.36
Targeted final palm fruits weight [g]	155	177.60	197.58	-
Actual final palm fruits weight after treatment [g]	154.95	175.78	197.32	-
Arrival of final moisture content [%wb]	6.57	16.64	26.02	29.27
Energy consumption [Wh]	123	78	36	-
Quality of extracted palm oil				
Oil Extraction rate [%]	33.80	30.33	8.13	3.32
FFA after extraction [%]	0.60 ± 0.01^{b}	0.76 ± 0.01^{a}	0.39 ± 0.03^{c}	0.47 ± 0.03^{d}
FFA after storage 14 day [%]	0.50 ± 0.02^{c}	0.38 ± 0.01^{d}	3.56 ± 0.01^{b}	32.24 ± 0.06^{a}
DOBI after extraction	6.74 ± 0.82^{a}	6.25 ± 0.17^{a}	4.65 ± 0.36^{b}	2.99 ± 0.18^{c}

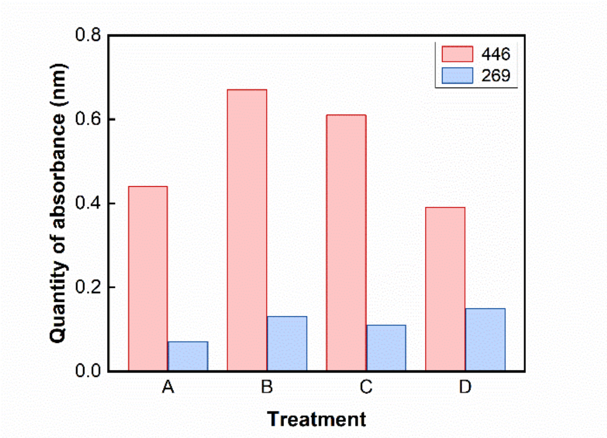

Figure 4. The measurement of absorbance at 269 nm (secondary oxidation) and 446 nm (carotene) after storage for 14 days.

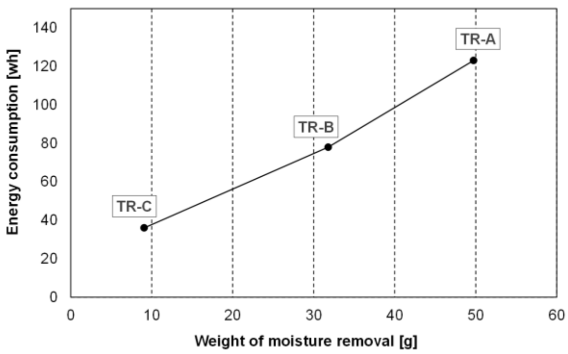

Figure 5. The correlation between energy consumption and weight of moisture removal.

In Fig. 5, which consists of the amount of energy consumption under microwave sterilization that relates to moisture removal in the treated group control. It can be seen that as long as palm fruits was sterilized longer, and more water was removed that required more energy consumption.

TABLE II. THE CROSS-SECTION APPEARANCES OF THE TREATMENT PALM FRUITS

Treatment (group)	Physical Appearance of microwave treated palm fruits	Mesocarp	Kernel
A) 5%wb		Dried and hardened	slightly brown
B) 15%wb		Greasy and hardened	White
C) 25%wb		Slightly greasy and soft	White
D) No treatment		Natural	White

In this study, the lowest moisture control was set at 5%, the sufficient energy required, was measured of around 120Watt-hour (Wh). This value was approximately 40Wh higher for eliminating moisture out to be 15% and three times greater compared for control 2004 g the moisture residue of oil palm fruits at 25%. Since all the treatment was controlled with the same conditions of microwave power at 800 watts, the proportion of energy consumption was divided by the weight of moisture removal(g) at approximately 2.1-2.4 Wh/g. Nevertheless, when some parameters changed, for instance, batch size or power of heating, the amount of this portion will also be changed certainly to match the correlation.

In order to find the optimal condition for the treated group of palm fruits by which moisture residue was controlled at as 25%, 15% and 5%, there are four categories for consideration following: 1. The physical condition of kernel as it should be kept in the same condition for oil kernel extraction. 2. Crude palm oil quality. 3. Amount of energy consumption. 4. Oil extraction rate from Table III, generally, a suitable condition must be met to all constraints but the actual requirement might be different based on the local market. Unfortunately, the results from treatment A showed a positive data, which all measured palm oil qualities (FFA, DOBI, and OER) were good, except if a decomposed kernel was not found.

TABLE III. COMPARISON RESULTS IN 5 CATEGORIES BASED ON THE GIVEN CONSTRAIN

Treatment	Kernel	FFA 14-Day	DOBI 14-Day	Energy	OER
A	✕	✓	✓	+ + +	+ + +
B	✓	✓	✓	+ +	+ +
C	✓	✓	✓	+	+

Considering the given results between treatment B and C which fitted to all constraints. While consumed energy from Tr-B was higher than Tr-C, it was reimbursed with higher OER and DOBI value together with the changing of FFA without a possibility of increment during storage for 14 days.

Summary in part A: In conclusion, the investigation in the first part had been made to find the proper condition of oil palm fruits sterilization under the microwave technique. The ranging of moisture residue was done by firstly, estimation of an initial weight and moisture content and secondly, sterilizing its weight to close to the targeted moisture control at 5%, 15%, and 25% respectively. Next, all groups were then extracted oil for checking the qualities. Based on the five important constraints, treatment B (15% of moisture residue) was selected to be the best condition.

The 15% of moisture residue will be further investigated in part II to verify the obtained result. Its condition will also be performed by varying two main factors as mass and power with two levels. The objective of this approach will be to ensure that moisture residue can be applied as one significant factor to guarantee whether the palm oil qualities are good or not.

B. Part B: Verifying Parameter in Term of Two Level of Power and Initial Mass with 15%wb of Moisture Control

The experiment in part II shows the design of an experiment that had been done in order to verify the 15% of moisture residue as one indicator as a process control parameter in the practical sterilization process.

There are two main factors that were designed, power & mass of the sample and determining with two levels for those factors as shown in Table IV. Therefore, the total number of running treatment bases on the combination treatment is equal to 20 runs (2 factors × 2 levels × 5 replications). The process of sampling palm fruits for each one had been done with the same methodology as described in part I for ensuring a normality withing a group. In addition, all of these 20 runs were done with different examiners who determined to manipulate all tasks of the experiment completely within a day due to prevent any time influence and any bias that might have occurred during experiment.

TABLE IV. DESIGN OF EXPERIMENT FOR SCREENING TEST AT 15% OF MOISTURE CONTROL IN PART II

Factor	Level	Range
Power	2	High (H) 800W Low (L) 400W
Weight of sample	2	300g and 100g

According to the given result Table V, the concept of dehydrating moisture out to the desired level at 15% was proven to be practical even when changing examiners. The arrival of final moisture content in each treatment was not far from the target, ranging from 12.13-15.18%. Next, all treatments were then extracted crude oil, Fig. 6 illustrates a scatter plot of FFA and DOBI of crude palm oil at 15% moisture residue after storage for and DOBI from all treatments stood with a positive result 14 days. It can be obviously seen that both values of FFA within standard requirements (FFA not exceed 5, immediately after finishing the sterilization process and crude palm oil was stored at the same environmental condition for 14 days to analyze the palm oil qualities again.

Fig. 6 illustrates a scatter plot of FFA and DOBI of crude palm oil at 15% moisture residue after storage for 14 days. It can be obviously seen that both values of FFA and DOBI from all treatments stood with a positive result within standard requirements (FFA not exceed 5, DOBI not lower than 2). Its FFA value fluctuated between 0.94% and 2.07% and DOBI was relatively stable at around 5 from the run of treatment 1 to 15 (Tr.1, Tr.2, Tr.3) but some other runs found higher in no.17–20 at almost 7.

From Table VI, two-way analysis of variance (two-way ANOVA) is used to compare the mean differences between two independent variables of power vs mass, there is no significant difference on the result of FFA as P-values is higher than 0.05. Namely, equivalent palm fruits at the initial stage with dehydrated moisture at the 15% target can assure the FFA value even if changing some factors of mass or power of the microwave with 95% confidence interval. On the contrary, DOBI shows a significant difference indicating that the probability to control the same level of DOBI with 95% confidence level is certainly not absolute, this because the statistical significance shows that there are influent factor from power, mass and combination between power and mass as the P-values was 0.022, 0.008 and 0.029 respectively.

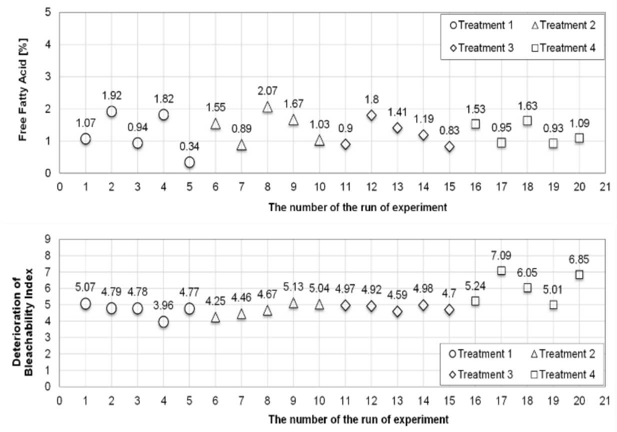

Figure 6. The results of the FFA and DOBI of palm oil at targeted 15% from 20 treatments.

Thus, when considering the initial value of absorbance at 446 and 269 nm which represents a total carotene and secondary oxidative, regarding Tukey's HSD (honestly significant difference) test which was selected for the pairwise comparison of two variables at 446 and 269 nm as shown in Table VII, based on the null hypothesis and alternative hypothesis, is all means are equal and not all means are equal respectively. There is no significant difference at 446nm as those were marked with the same capital letter "A", namely the initial value of total carotene in each group is considered equivalent with 95% confidence. However, the comparison result of secondary oxidation (269nm) shows that there is a dichotomy of "A" and "B", the secondary oxidation occurred during the storage of crude palm oil between (Tr.1&Tr.2) is different from (Tr.4), at $P \leq 0.05$. The absorbance of 269nm from Tr.4 was least among the others at average 0.135, therefore Tr.4 shows higher possibility to keep crude palm oil in a good level. Nevertheless, the discrimination between the values of DOBI whose came from a different pathway of factor should be considered more because its value might be affected by the various cause, for instance, ripeness of palm fruits, environmental condition during sterilization, mixing of crude palm oil, heat sources, exposure time and so on [8].

Summary in part B: The set of oil palm fruits with target moisture at about 15% have been verified again by varying the factor of power and mass with two levels. In addition, all examiners who examined this part differed from part I. The given result from all combinations can ensure that the palm oil qualities show the value of FFA and DOBI following standard requirements likely revealed from part I. The statistical analysis shows that there are no significant differences in the different pathways of treatment from the group of FFA, while DOBI inverts. However, the DOBI from all treatments still shows a rank of acceptable value since the average value stood at around 5 with the highest almost at 7 and the lowest at 3.96.

Therefore, whatever the conditional sterilization is used, to determine the target of residual moisture at about 15% is the one alternative solution to guarantee the oil palm fruit with the acceptable condition.

TABLE V. QUANTIFYING THE DESIRE AND ACTUAL VALUE OF MOISTURE CONTROL

The number of run and treatment		Power	Weight (g)	Initial weight (g)	Weight of moisture (g)	Targeted weight at 15% (g)	Arrival of final palm weight (g)	Arrival of final moisture content (%)
1	**Tr.1**	H	100	117	33.90	97.76	97	14.33
2		H	100	124	35.93	103.61	103	14.49
3		H	100	120	34.77	100.27	97	12.13
4		H	100	130	37.67	108.63	108	14.51
5		H	100	124	35.93	103.61	103	14.49
6	**Tr.2**	L	100	123	35.64	102.78	103	15.18
7		L	100	126	36.51	105.28	105	14.77
8		L	100	116	33.61	96.93	97	15.06
9		L	100	120	34.77	100.27	100	14.77
10		L	100	122	35.35	101.94	100	13.35
11	**Tr.3**	H	300	233	67.51	194.69	193	14.25
12		H	300	221	64.03	184.67	184	14.69
13		H	300	218	63.17	182.16	181	14.46
14		H	300	224	64.90	187.17	187	14.92
15		H	300	222	64.32	185.50	173	14.17
16	**Tr.4**	L	300	213	61.72	177.98	177	14.53
17		L	300	218	63.17	182.16	179	13.50
18		L	300	218	63.17	182.16	183	13.84
19		L	300	224	64.90	187.17	187	15.00
20		L	300	221	64.03	184.67	184	14.69

TABLE VI. STATISTICAL ANALYSIS THE INFLUENCE OF DIFFERENCE TREATMENT OF FFA AND DOBI

Respond	Factor	df	SS	MSE	F	P-value
FFA	Power	1	0.062	0.062	0.27	0.611
	Mass	1	0.005	0.054	0.23	0.636
	Power&Mass	1	0.062	0.062	0.27	0.611
	Error	16	3.723	0.232		
	Total	19	3.902			
DOBI	Power	1	1.959	1.959	6.47	0.022
	Mass	1	2.798	2.797	9.24	0.008
	Power&Mass	1	1.740	1.741	5.74	0.029
	Error	16	4.845	0.303		
	Total	19	11.343			

TABLE VII. MEANS THATARE SIGNIFICANTLY DIFFERENT BY TUKEY'S RANGE TEST

Treatment	Mean	Std	Confidence Interval (95%)	Grouping
At 446 nm				
1	0.992	0.205	0.854,1.129	A
2	0.962	0.121	0.825,1.100	A
3	0.844	0.154	0.706,0.982	A
4	0.776	0.064	0.638,0.914	A
At 269 nm				
1	0.214	0.040	0.184,0.243	A
2	0.206	0.021	0.176,0.235	A
3	0.179	0.038	0.149,0.208	A B
4	0.135	0.018	0.105,0.164	B

IV. CONCLUSION

The verification of 15% moisture residue is proved by varying the factor of power and mass at different levels. While power, the weight of mass and examiners in part II are different from part I, the given result can ensure that these all show the FFA and DOBI positive result with the standard requirements as same as the experiment results in part I.

In addition, the statistical analysis reveals that there are no significant differences in the different pathways of FFA, while DOBI inverts, since its value has significant value (P-value less than 0.05). However, the DOBI from all treatments still shows a rank of acceptable value since the average value stood at around 5 with highest almost at 7 and the lowest at 3.96.

In conclusion, the technique of controlling moisture residue in oil palm fruits is applicable in the general process of oil palm sterilization, both steam and non-steam sterilization. However, the final weight of oil palm fruits should be carefully controlled and evaluated the weight that equals the recommended moisture residue. However, the uniformity of initial moisture content in the large batch might be harder to control when compared with the smaller one. However, the topic of uniformity of targeted moisture residue should study furthermore to ensure the actual process.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Pornpipat Yoosa conducted the research, analyzed the data and wrote the paper; Siwaporn Srimongkol and Rattanapon Yuttawiriya conducted the research; all authors had approved the final version.

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References

[1] A. K. M. Omar, T. L. T. Norsalwani, M. S. Asmah, Z. Y. Badrulhisham, and A. Mat, "Implementation of the supercritical carbon dioxide technology in oil palm fresh fruits bunch sterilization: A review," *Journal of CO2 Utilization*, vol. 25, pp. 205-215, 2018.

[2] D. Of and B. Index, "Deterioration of bleachability index," no. 7, pp. 2-3, 2004.

[3] J. M. Jusoh, N. A. Rashid, and Z. Omar, "Effect of sterilization process on Deterioration of Bleachability Index (DOBI) of Crude Palm Oil (CPO) extracted from different degree of oil palm ripeness," *Int. J. Biosci. Biochem. Bioinforma.*, vol. 3, no. 4, pp. 322-327, 2013.

[4] R. H. V Corley and P. B. Tinker. [2003]. The oil palm. Blackwell Science, Oxford; Malden, MA. [Online]. Available: http://site.ebrary.com/id/10233069

[5] K. Sivasothy, R. M. Halim, and Y. Basiron, "A new system for continuous sterilization of oil palm fresh fruit bunches," *J. Oil Palm Res.*, vol. 17, pp. 145-151, 2005.

[6] I. Umudee, M. Chongcheawchamnan, M. Kiatweerasakul, and C. Tongurai, "Sterilization of oil palm fresh fruit using microwave technique," *International Journal of Chemical Engineering and Applications*, vol. 4, no. 3, pp. 111-113, 2013.

[7] S. F. Cheng, M. N. L, and C. H. Chuah, "Microwave pretreatment: A clean and dry method for palm oil production," *Ind. Crop. Prod.*, vol. 34, no. 1, pp. 967-971, 2011.

[8] N. M. Han, C. Y. May, and M. A. Ngan, "Dry heating of palm fruits: Effect on selected parameters," *Am. J. Eng. Appl. Sci.*, vol. 5, no. 2, pp. 128-131, 2012.

[9] R. Heating, A. Choto, C. Thongurai, N. Kladkaew, and M. Kiatweerasakul, "Sterilization of oil palm fruit using radio-frequency heating," *Int. J. Adv. Chem. Eng. Biol. Sci.*, vol. 1, no. 1, pp. 123-126, 2014.

[10] E. Karrar, S. Sheth, W. Wei, and X. Wang, "Effect of microwave heating on lipid composition, oxidative stability, color value, chemical properties, and antioxidant activity of gurum (Citrulluslanatus var. Colocynthoide) seed oil," *Biocatal. Agric. Biotechnol.*, vol. 23, no. 1, p. 101504, 2020.

[11] K. Kanjanapongkul, "Single and combined effects of ohmic and microwave heating on crude palm oil quality and stability," *Agric. Nat. Resour.*, vol. 55, no. 2, pp. 177-186, 2021.

[12] M. C. Chow and A. N. Ma, "Processing of fresh palm fruits using microwaves," *Journal of Microwave Power and Electromagnetic Energy*, vol. 7823, no. 3, 2016.

[13] M. S. Rahman and S. A. Al-Farsi, "Instrumental Texture Profile Analysis (TPA) of date flesh as a function of moisture content," *J. Food Eng.*, vol. 66, no. 4, pp. 505-511, 2005.

[14] N. Rajanaidu and B. K. Tan, "Variability of Fatty Acid Composition (FAC) within bunches in the oil palm Elaeis guineensis," *Oleagineux (France)*, vol. 38, pp. 581-584, 1983.

[15] F. S. Ali, R. Shamsudin, and R. Yunus, "The effect of storage time of chopped oil palm fruit bunches on the palm oil quality," *Agric. Agric. Sci. Procedia*, vol. 2, pp. 165-172, 2014.

[16] C. J. Vincent, R. Shamsudin, and A. S. Baharuddin, "Pre-treatment of oil palm fruits: A review," *J. Food Eng.*, vol. 143, pp. 123-131, 2014.

[17] O. M. Lai, C. P. Tan, and C. C. Akoh, *Palm Oil: Production, Processing, Characterization, and Uses*, Elsevier, 2015.

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