The Effects of Controlling the Residual Moisture Content in Oil Palm Fruits under Microwave Sterilization

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***Abstract*—Sterilization is a key process in palm oil production because it can affect the production capability and crude palm oil quality. Due to extensive development of steamless (dry heating) palm oil extraction technology in Thailand, efforts of using dry sterilization process have been made. More specifically, several studies in microwave heating on oil palm fruits have been conducted due to its advantages. In the current work, the effects of controlling the residual moisture content in oil palm fruits and its application as a quality guideline in microwave sterilization process were studied. The results of the study revealed that a promising residual moisture content of 5 - 15% wet basis of microwave-treated palm fruits could preserve the fruits with relatively good physical appearances without fungi or destructive effects from microwave energy. In addition, enzymatic lipolysis was also inactivated by optimal microwave heating, which can be obviously seen by the negligible increment of free fatty acid during 15 days of retention compared to improperly treated palm fruits.**

***Index Terms*—oil palm sterilization, microwave sterilization, microwave-treated palm fruit, residual moisture content, preservation, palm oil quality**

I. Introduction

Oil palm is an agricultural commodity which is abundant in tropical countries. Indonesia, Malaysia, and Thailand are the world's leading producers of palm oil. In 2016, the report from Office of Agricultural Economics, Thailand [1] showed that there were approximately 722,509 hectares of oil palm plantations and 10,948,884 tonnes of fresh fruit bunch (FFB) production. Moreover, the expansion of oil palm plantations has been continuously promoted by the national policy and consumption demand.

Generally, palm oil milling processes in Thailand can be broadly classified as (1) a well-known conventional steaming process, which is the same as those processes used in Malaysia and Indonesia and (2) a steamless process, which mostly uses hot air as a heating medium. The majority of small palm oil mills have adopted the steamless process due to low investment cost, low maintenance cost, and no wastewater effluent [2].

Usually, in Thailand, FFBs are supplied to palm oil mills by intermediaries who collect them from oil palm planters. However, two typical steps of FFB transportation, from plantation sites to intermediary centers and from intermediary centers to the mills, can deteriorate palm fruits in FFBs, which result in degradation of oil palm quality. During these steps, it is found that piling up FFBs in many stacking layers carelessly is the main reason of bruises and damages on palm fruits, which causes the increase of free fatty acid (FFA) content [3]. In addition, longer processing time of FFBs from plantation sites to the mills also causes the increase of FFA content [4]. Under this situation, small palm oil mills, which use loosed palm fruits mostly from oil palm collection centers, do not have other choices but only using bruised and damaged palm fruits. Therefore, palm oil produced by most of small palm oil mills is below the standard. One of the possible approaches to solve this problem is to preserve palm fruits arriving at the collection centers by using a dry heat sterilization technique.

Although there are several methods for dry heat sterilization to preserve oil palm fruits, such as hot air heating and microwave heating, the microwave heating method is considered to provide various advantages over the others, such as high energy efficiency, reduced heating time, and drying quality improvement [5]. A study by Chow and Ma [6] indicated that the effects of microwave heating on palm fruits should carefully be controlled such that an exposure time is 3 min and a heating temperature does not exceed 100 ℃ in order to keep high levels of vitamin E and carotene. They also found that the residual moisture content from various exposure times did not affect the FFA content. However, their findings are limited to FFA measured from the oil immediately extracted from the fruits after sterilization without the effect of fruit storing time. Another interesting research of oil palm fruit drying with microwave oven by Cheng *et al.* [7] presented that the suitable drying time should be 3 min in order to achieve the acceptable palm oil yield of 20%. Nonetheless, the best qualities of palm oil containing high levels of vitamin E and carotene were obtained by a shorter period of drying time at 2 min. However, their recommended conditions seem to be imperfect when considering the

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physical appearances of palm fruits where decomposition at the center of kernel and mesocarp occurred. Similar study of oil palm treatment by microwave conducted by Umudee *et al.* [8] showed that microwave heating can halt the FFA increment under the appropriate condition of heating power at 360 W and exposure time between 10-15 min. Using this condition, the monitored temperature of mesocarp should be between 50-80 ℃.

Based on the previous studies mentioned above, we found that the suitable condition from each study is specific and different from each other. For example, when the weight of oil palm fruits is changed, the suitable heating power and exposure time will also change. This is because heating power and exposure time together represent energy put into the system to remove a certain amount of water, which is an extensive property whose value depends on the weight and initial moisture content of the fruits. To establish more general conditions that can be applied to any weight and any initial moisture content of the fruits, the residual moisture content in the fruits, which is an intensive property, is proposed as a condition to be controlled during microwave heating.

In this paper, the study is divided into two parts. The first part (Part A) is to prove that most of constituents removed from palm fruits during microwave heating are water as long as there is some moisture left in the fruits. To prove this phenomenon, three experiments were conducted in order to investigate the weight changes of (a) pure water and dried palm fruits, (b) fresh palm fruits and dried palm fruits, and (c) only dried palm fruits. The second part (Part B) is to study the effects of the residual moisture content of palm fruits on the physical appearances and FFA content. In this part, the experiment consists of five treatments with the residual moisture contents of 5, 10, 15, and 20% wet basis (wb). The discussions for this part will be separated into two sections. The first section (B1) focuses on the weight change profile of heated palm fruits, as well as the final residual moisture contents, and the second one (B2) focuses on the influences of palm fruit storage time.

II. Materials and Methods

A. Materials

FFBs were obtained from an oil palm collection center in Saraburi province, Thailand. The palm fruits were, then, manually detached from the bunches and their stalks using hands and an axe. All unbruised fruits selected for the experiments were prepared within 3 days after the FFB collection and were kept at ambient temperature in the laboratory. Dried palm fruits were also prepared by drying some of the selected palm fruits in a hot air oven at 105 ℃ until no weight change was observed over three hours. This was to ensure that negligible moisture was left in the dried palm fruits and nothing else besides water was removed from the fruits.

B. Microwave Oven

The Toshiba ER-G23SC, 800 W output, 2450 MHz, turn-table microwave oven was used for all microwave heating of palm fruits. Its weight was 11.5 kg approximately. Only high power level (800 W output) was utilized in all microwave heating experiments.

C. Moisture Removal from Palm Fruits under Microwave Heating

Three experiments for investigating the weight changes of (a) pure water and dried palm fruits, (b) fresh palm fruits and dried palm fruits, and (c) only dried palm fruits were set up by using the microwave oven with 800 W power output for 4 min. For each time increment of 1 min, the heating was paused shortly to measure the temperature of the heated materials (palm fruits and pure water) by using a thermal camera, Flir I5 (Flir Systems, USA) and to weigh each material individually by using an electronic balance, AND GF-1000 (A&D, Japan). It should be noted that each material was also weighed individually at the beginning of the experiments.

In experiment (a) pure water and dried palm fruits, 200 g of pure water in a beaker and 5 dried palm fruits (about 100 g) in a petri dish were heated with the microwave oven at the same time. Similarly, in experiment (b) fresh palm fruits and dried palm fruits, 5 dried palm fruits (about 93 g) and 5 fresh palm fruits (about 106 g) were heated at the same time. Finally, in experiment (c) only dried palm fruits, 5 dried palm fruits were heated.

D. Calculation of Targeted Weight of Dried Palm Fruits for Residual Moisture Content Control

The selected fresh palm fruits were divided into 5 piles, Pile-A, -B, -C, -D, and -E, each weighed about 1 kg as shown in Fig. 1. In each pile, 5 fruits (about 100 g) were sampled to determine the initial moisture content by using a gravimetric method. Each sample was dried in a hot air oven until the weight change was considered to be negligible. The initial wet basis moisture content of each sample, $MC_w(0)$, can be expressed as:

$$MC_w(0) = \frac{W_{s,ini} - W_{s,final}}{W_{s,ini}} \cdot 100 \tag{1}$$

where $W_{s,ini}$ is the initial weight of sampled palm fruits and $W_{s,final}$ is the final weight (moistureless) of sampled palm fruits.

The initial wet basis moisture content value of each 100 g sample, $MC_w(0)$, was used to represent an estimate in each pile. The moistureless weight, W_{dried}, of the remaining palm fruits about 900 g of each pile, which will be used for further experiments, was calculated by using the following equation:

$$W_{dried} = \left(\frac{100 - MC_w(0)}{100}\right) \cdot W(0) \tag{2}$$

where $MC_w(0)$ is the initial wet basis moisture content of each 900 g pile obtained from (1) and $W(0)$ is the initial weight of each pile.

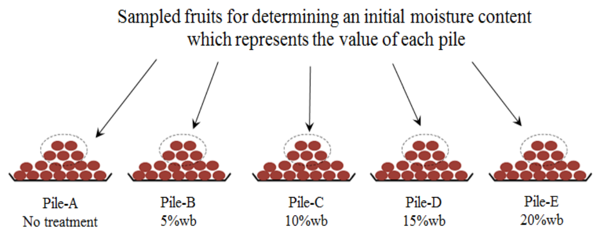


Figure 1. Dividing the selected unbruised palm fruits into 5 piles before applying the treatments.

While Pile-A was kept without any treatment, Pile -B, -C, -D, and -E were heated in the microwave oven individually to approach the desired moisture contents. The targeted weight, W_{target} of each palm fruit pile can be calculated by the following expression:

$$W_{target} = \frac{100 \cdot W_{dried}}{100 - MC_{desired}} \qquad (3)$$

where $MC_{desired}$ is the desired moisture content that is 5%wb, 10%wb, 15%wb, and 20%wb for Pile -B, -C, -D, and -E, respectively.

In order to obtain the desired moisture contents while the palm fruits were being heated in the microwave oven, this oven and the fruits were weighed using a scale as shown in Fig. 2. The weight was recorded for each 1-min time increment until it was close to the targeted weight.

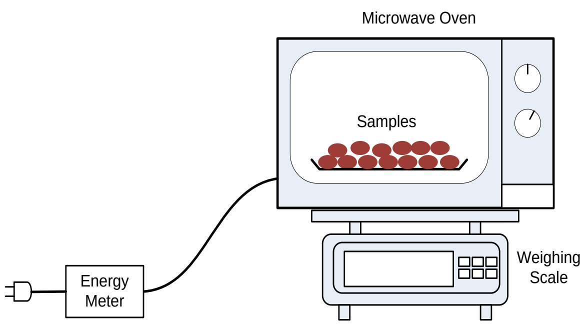


Figure 2. Schematic of the experimental setup for drying palm fruits in microwave oven and weighing the fruits on scale.

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 0th, 5th, 10th, and 15th day. On the measuring day, palm oil was extracted from the sampled fruits of each conditional treatment for approximately 1.0 g ($\pm$0.05 g), which were then kept in the glass tube individually, and finally FFA content was measured by using automatic tritator 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: Moisture Removal from Palm Fruits under Microwave Heating

The aim of these experiments is to prove that most of constituents removed from palm fruits during microwave heating are water as long as there is some moisture left in the fruits. The weight profiles of samples, i.e., (a) dried palm fruits vs. pure water, (b) dried palm fruits vs. fresh palm fruits, and (c) only dried palm fruits, in 4-min duration of dry heating under microwave exposure are shown in Fig. 3.

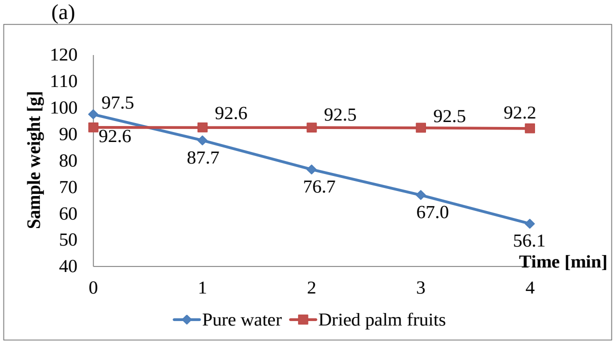
In Fig. 3(a), the weight of pure water decreases from 97.5 g to 56.1 g (41.4 g or 42.46% decrement) whereas that of dried palm fruits decreases from 92.6 g to 92.2 g (0.4 g or 0.43% decrement). It is clearly seen that the weight of the pure water decreased rapidly due to vaporization, while the weight of the dried palm fruits decreased almost negligibly. This implies that most of the vaporized constituents are water, rather than oil, mesocarp, or kernel in dried palm fruits, when all are present together in the microwave heating chamber. It is, therefore, likely that most of the vaporized constituents are water when both palm fruits with high moisture content and those with negligible moisture content are present together. This implication is supported by the results shown in Fig. 3(b), which will be discussed as the following.

Fig. 3(b) demonstrates the weight changes of two different kinds of palm fruits: fresh palm fruits and dried palm fruits, which were neatly chosen in order to ensure that the weights and other physical properties were equivalent as much as possible. It can be seen that the weight of the fresh palm fruits decreased quickly from 105.7 g to 89.6 g (16.1 g or 15.23% decrement) in the first 2 min and then slightly from 89.6 g to 89.0 g (0.6 g or 0.67% decrement) in the last 2 min, whereas the weight of the dried palm fruits decreased negligibly from 90.6 g to 88.7 g (1.9 g or 2.09% decrement).

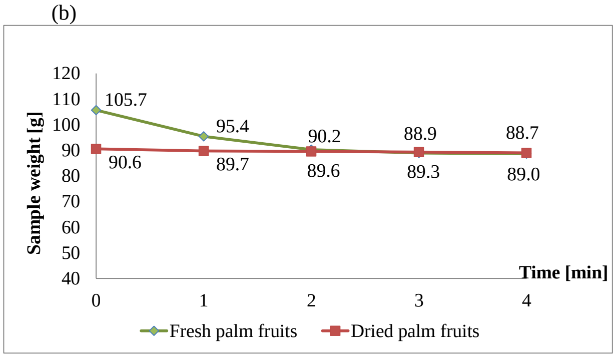
Since the dried palm fruits were prepared under hot air drying at 105°C, they were made up of all constituents that fresh palm fruits would be, except water, (i.e. oil, mesocarp, kernel). If these constituents existing in the dried palm fruits were removed during microwave heating, we would expect to see a significant weight decrease of the dried palm fruits in Fig. 3(b). Since this is not the case, we can infer that, in this case, nothing else besides water was removed from dried palm fruits. In addition, since the weight of the fresh palm fruits quickly decreased at the beginning of the heating process and slowly approached the weight of the dried palm fruits, we can also infer that nothing else besides water was removed from the fresh palm fruits.

In Fig. 3(c), when only dried palm fruits were present in the microwave heating chamber, the weight of the fruits decreased from 98.3 g to 93.1 g (5.2 g or 5.3% decrement). The average rate of weight decrement in this case is 1.3 g per min per sample while that of the previous experiment is 0.5 g per min per sample. This implies that the rate of weight decrement can increase and the weight decrease can become significant if dried palm fruits are continued to be heated in a microwave oven.

(a)



(b)



(c)

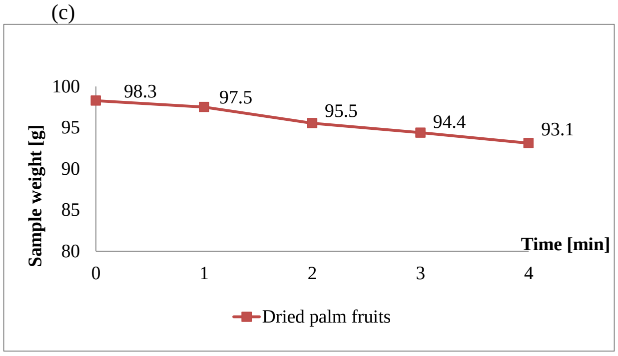
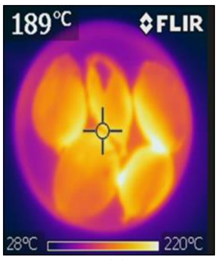


Figure 3. Weight profiles of (a) dried palm fruits vs. pure water, (b) dried palm fruits vs. fresh palm fruits, and (c) dried palm fruits only.



(a)

(b)

Figure 4. Temperature distribution and physical appearances of dried (moistureless) palm fruits after being continuously heated in the microwave oven.

Fig. 4 shows the temperature distribution and physical appearances of the dried palm fruits after being continuously heated in the microwave oven. It can be seen that the temperature was raised very high and the kernels completely turned black. This is because, in this case, there is no moisture remained in the dried fruits and other constituents of high boiling points (i.e. oil, mesocarp, kernel) had to absorb the microwave energy until they became destroyed from the excess energy [9].

According to the experimental results, it can be stated that the residual moisture content plays an important role in microwave-heated palm fruits. The results lead to the following conclusions in this part as below:

- Most of constituents removed from palm fruits during microwave heating are water as long as there is some moisture left in the fruits.
- The higher moisture content of fresh palm fruits can absorb more microwave energy than the lower ones.
- Palm fruits under microwave treatment tend to be deteriorated when there is no moisture left in the fruits.

From the above conclusions, microwave heating is capable of controlling the weight loss of moisture in palm fruits.

B. PART B: B1) Weight Change Profile of Heated Palm Fruits and the Final Residual Moisture Contents

Fresh palm fruits of Pile -B, -C, -D, and -E were treated by microwave heating to their targeted weights in order to achieve the desired moisture contents. The targeted weights of the palm fruit piles were calculated based on their desired moisture contents using (3). Due to the limitation of 1-min time duration before each sampling, the final actual fruit weights may only approximately meet the calculated ones. The parameters and results of all piles are summarized in Table I.

Fig. 5 shows one of the oil palm fruit weight profiles of Pile-B under microwave heating against time for the desired residual moisture content of 5%wb. From Fig. 5, it can be seen that the palm fruit weight decreased slowly in the earlier stage (0-6 min). This is because the moisture and other constituents of palm fruits were being heated up. For the next stage (6-20 min), when the moisture was heated up to its boiling point, vaporization occurred rapidly and the rate of weight loss became faster than that in the earlier stage. In the final stage (20-26 min), it should be noticed that the rate of weight loss was reduced because the amount of the remaining moisture content became small. In this situation, if the palm fruits being dried were continued to be exposed to the prolonged heating time, the other constituents in the fruits could be thermally decomposed [9].

TABLE I. PARAMETERS AND RESULTS OF DRYING PALM FRUITS UNDER MICROWAVE TREATMENT

	Pile-A No treatment	Pile-B Desired 5%wb MC	Pile-C Desired 10%wb MC	Pile-D Desired 15%wb MC	Pile-E Desired 20%wb MC
Initial palm fruit weight [g]	910	906	854	940	925
Initial moisture content [%wb]	29.61	31.13	29.15	32.28	30.45
Targeted final palm fruit	-	656.80	672.29	748.90	828.51

Figure 5. Physical appearances of palm fruits on 0th day and 15th day.

weight [g]					
Actual final palm fruit weight after treatment [g]	-	658.00	680.00	748.00	828.00
Actual of final moisture content [%wb]	-	5.17	11.02	14.90	19.95

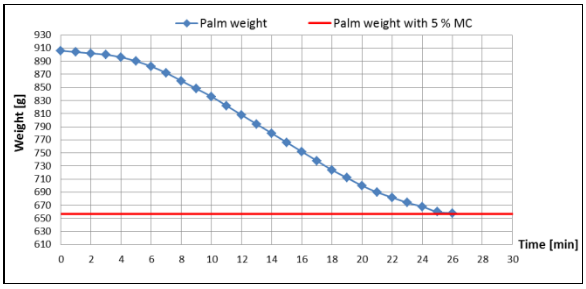


Figure 6. Weight profile of palm fruits of Pile-B with the desired moisture content of 5%wb.

C. PART B: B2) Influence of Palm Fruit Storage Time on Physical Appearances and Free Fatty Acid Content

Palm fruits after processing in each condition were stored in the ambient environment where temperature and relative humidity were around 28 ℃ and 65%, respectively. The physical appearances of untreated palm fruits (Pile-A) and microwave-treated ones (Pile-B, -C, -D, and -E) on 0th and 15th day are depicted in Fig. 6. For untreated palm fruits (Pile-A) and the most lightly microwave-treated ones (Pile-E), their exocarp looked mostly damp and bruised. On 15th day, fungi randomly appeared in some of the fruits in both Pile-A and Pile-E while the other treated palm fruits, including those in Pile-B, Pile-C, and Pile-D still looked dried without damp or any fungi.

Table II shows the cross-sectional views of untreated palm fruits (Pile-A) and the most severely treated palm fruits (Pile-B). Regarding the quality of kernels, it can be seen that the kernels from the most severely microwave-treated palm fruits with the smallest amount of 5%wb moisture content did not have any browning, cracking, or even burning. When considering the physical appearances of mesocarp, it was found that the mesocarp was slightly hardened, compared to that of the untreated palm fruits. This study, therefore, suggests that oil palm fruits can be microwave-treated to lower the residual moisture content down to 5%wb without causing any thermal damages to the fruits.

TABLE II. The Cross-Section Appearances of the Untreated (Pile-A) and Treated (Pile-B) Oil Palm Fruits

Palm fruits	Mesocarp	Kernel	
Pile-A No treatment	Moist	White	
Pile-B Desired 5%wb MC	Drier than Pile-B	White	

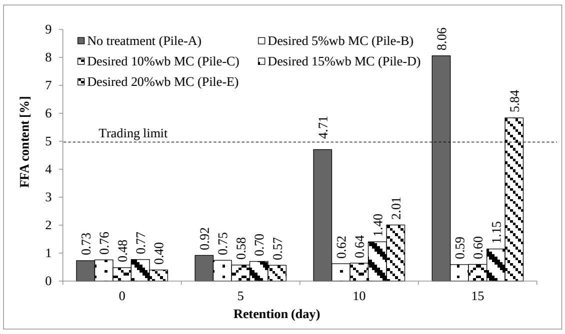


Figure 7. The FFA content from five different treatments in every five consecutive day.

FFA content is one of the important parameters used to monitor the palm oil quality. Fig. 7 shows the FFA contents of treated and untreated palm fruits in every five consecutive days. The FFA content of untreated palm fruits (Pile-A) was observed to be significantly low at 0.73% on the 0th day and increased rapidly after 5 days. Finally, on the 15th day, it increased to 8.06%, much higher than the standard limit of 5% for trading purpose [10]. In the same figure, the FFA contents of the microwave-treated palm fruits in Pile-B, -C, and -D are clearly seen to be kept within 5% (ranging from 0.58% - 1.4%) for any storage time up to 15 days while those in Pile-E reaches 5.84% on the 15th day. The results demonstrates that microwave treatment on oil palm fruits such that their residual moisture content is within 5%wb to 15%wb is able to sufficiently halt the enzymatic activity that causes the increase of FFA content. Under these appropriate treatment conditions, oil palm fruits can be preserved for at least 15 days. In terms of 15-day FFA increment, which is the FFA increased from 0^{th} day to 15^{th} day, Fig. 8 shows that the FFA increment is directly proportional to the residual moisture content in palm fruits.

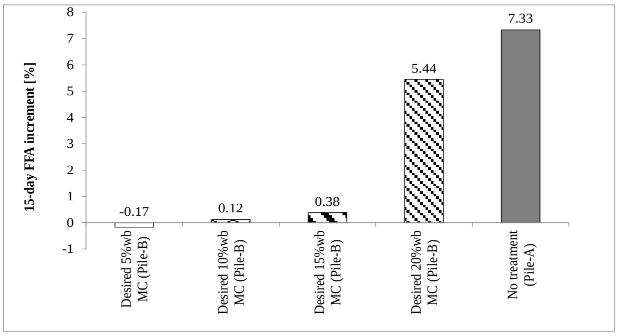


Figure 8. The relationship between the 15-day FFA increment and the residual moisture content.

IV. Conclusion

The effects of controlling the residual moisture content in oil palm fruits under microwave sterilization were studied. It is shown that suitable conditions of treated palm fruits such that their residual moisture contents are within 5%wb and 15%wb can provide promising results in terms of better physical appearances and free fatty acid contents of palm fruits. More specifically, the kernels can be maintained in good quality without decomposition from the microwave overheating and the fruits can be preserved for at least 15 days without the appearing of bruises and fungi or even exceeding the standard limit of free fatty acid content. The experimental results in this study indicated that the residual moisture content played an important role for the quality criteria in the microwave sterilization process. However, this study does not cover the effects of microwave treatment on other palm oil qualities, such as vitamin E and carotenes, which should be further investigated.

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References

[1] Office of Agricultural Economics Thailand. (2013). *Agricultural Product in Thailand*. [Online]. Available: www.oae.go.th/ewt-news.php?nid=13577

[2] E. Viyanit, T. Tantanawat, U. Sahapatsombut, N. Intranont, and S. Nivitchanyong, "Prototype development of steamless palm oil extraction system for using in small-scale community enterprises," in *Proc. XVIII International Symposium on Alcohol Fuels*, India, 2010, pp. 188-189.

[3] N. Rajanaidu and B. K. Tan, "Variability of fatty acid composition (FAC) within bunches in the oil palm," *Elaeis. J. Oleagineux*, 1983.

[4] C. Marcus and C. Sophie, *Oil Palm Expansion in South East Asia: Trends and Implications for Local Communities and Indigeneous Peoples*, 1st ed, 2011, pp. 24-49.

[5] A. C. Metaxas and R. J. Meredith, *Industrial Microwave Heating.* London: Oeter Peregrinus Ltd., 1983, p. 126.

[6] M. C. Chow and A. N. Ma, "Processing of fresh palm fruits using microwaves," *International Microwave Power Institute*, pp. 165-173, 2007.

[7] S. F. Cheng, L. N. Mohd, and C. H. Chuah, "Microwave pretreatment: A clean and dry method for palm oil production," *Industrial Crops and Products*, vol. 34, pp. 967-971, 2011.

[8] I. Umudee, M. Chongcheawchamnan, M. Kiatweerasakul, and C. Tongurai, "Sterilization of oil palm fruit using microwave technique," *Journal of Chemical Engineering and Applications*, vol. 4, no. 4, 2013.

[9] M. Maskan, "Drying, shrinkage and rehydration characteristics of kiwi fruits during hot air and microwave drying," *Journal of Food Engineering*, vol. 48, no. 2, pp. 177-182, 2001

[10] S. Nor'aini and W. L. Siew, "Quality control measures in the palm oil industry," Palm oil Dev.

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