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Effects of Microwave Heating on Oil Palm Mesocarp

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Sterilization is an essential pre-treatment step in crude oil extraction process as to retain the quality and minimize the enzymatic activity within the fruits. This pre-treatment process on fresh fruit bunches often involves a large amount of steam and pre-treatment processes. Hence, this produces a large amount of palm oil mill effluent (POME) and empty fruit bunch wastes. Moreover, additional drying processes are required to reduce the fruits' moisture content for quality and storage purposes. Microwave energy is perceived as an alternative bringing improvement to the current process by introducing rapid heating as well as to improve process efficiency. The rapid heating process can effectively reduce power, energy and time required, yet capable of achieving the desired temperature through interaction between microwave, polar water molecules and charged ions in fresh fruit bunches. Other than that, microwave pre-treatment is a good alternative as it not only reduces the moisture content of fresh fruit bunches but also eliminates the production of POME, which is inevitable in the current process. Therefore, microwave technology is regarded as a clean process in the fresh fruit bunches pre-treatment. This paper reports the effects of microwave on the flesh of the oil palm fruits - mesocarp. Moisture content, dimensions and structure of the mesocarp are evaluated. The experimental results show that under the microwave treatment, the drying time required to reduce the moisture content of the mesocarp to 10 %, at power levels of 50 – 200 W, ranged from 2 – 35 min with the reduction of dimensions ranged from 3.6 – 6.2 %. Although varying the power level of microwave showed some degree of shrinkage, no significant changes were observed on the surface of the mesocarp. The experimental results demonstrated that microwave drying could provide a quicker drying process that resulted in least destruction occurred on the surface of the mesocarp.

1. Introduction

Palm oil is extracted from mesocarp of oil palm fruits through the oil palm milling process. Sterilization, is the first stage of the milling process where fresh fruit bunches (FFB) is cooked using high-pressure steam operated at 15-45 psi for about 90 min in horizontal cylinder autoclaves (Sivasothy and Rohaya, 2000). The sterilization process requires a large amount of steam to supply heat to FFB. The supplied heat encourages softening and easy detachment of the fruits from the FFB. The heat supplied also aimed to destroy the lipase in the fruits to prevent enzymatic activity that causes rises in Free Fatty Acid (FFA). Nevertheless, nearly half of the steam used ended as palm oil mill effluent (POME), a waste generated from the milling process (Ahmed et al., 2015). POME is declared as one of the major environment pollutants and requires an expensive and difficult treatment before disposal (Madaki and Seng, 2013). Current sterilization process that involves mechanical wet process using hot steam has not changed since palm oil was commercially produced in Malaysia since 1970s. Hence, there is an urge to look for alternative sterilization process.

The use of microwave energy has been introduced widely in numerous food processing industries since 1990s (Rahman, 2007). The adoption of microwave processing has offered a number of advantages such as volumetric heating, short process time, energy savings and non-contact heating (Vincent et al., 2014).

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In microwave heating, microwave energy absorbed by a material through the interaction between microwave with the ionic constituent movements and the polar molecules in the material. In contrast, the current oil palm sterilization process involves the conventional thermal processes whereby heat is transferred from the surface of a material to its interior through convection, conduction and radiation. Therefore, the volumetric heating offered by the microwave drying technology gives a faster heating rate as compared with the current sterilization process. In the previous works by Chow and Ma (2007) and Cheng et al. (2011), microwave technology was introduced as a pre-treatment process to replace the current sterilization process. The microwave pre-treatment were combined with solvent extraction to extract oils from the fruits. Their results showed palm oil and kernel oil of better quality were extracted as compared to the commercial products. In addition, production of POME was eliminated in the microwave sterilization process. Therefore, microwave-heating technology is regarded as a green and fast pre-treatment process which could be employed in the palm oil sterilization process.

Microwave pre-treatment are often used to speed up the drying process, reduce the initial moisture content, and improve the quality of dried foods (Sobhy and Chaouki, 2010). The quality of dried foods can be attained by inhibiting enzymatic activity which could cause rises in FFA. A minimum total moisture content of 15 % in an oil palm fruits needs to be achieved to prevent the increased of FFA (Okolo and Adejumo, 2014). The removal of moisture content affects the physical alterations of foods. The physical alterations include shrinkage and damaged to its microscopic structure. Shrinkage is resulted from the pressure imbalance between the interior and the exterior of the heated material, which leads to volume changes. In general, shrinkage is almost linearly correlated with its moisture content in foods for example, strawberries (Raghavan and Venkatachalapathy, 1999) and pears (Guiné et al., 2006). Shrinkage has a negative impact on the quality of dried product in terms of its wettability, texture changes and absorbability. In addition, the internal structure of food will be deformed and locally damaged during a drying process. Changes in food structure have an influence on its textural, quality and nutritional attributes (Fazaeli et al., 2012). Therefore, food structure is too an important factor to determine the food quality.

Understanding the thermal behaviour of a material is essential to monitor its thermal properties for the usage of the material in thermal processes. Thermal analysis has become an important method used in the thermal properties characterization. The rate of weight loss of the sample in a specific temperature ranges provides an indication of its thermal stability from the decomposition reactions. The analysis is an important tool to determine the temperature where degradation of the material occurs. Further studies need to be carried out especially in determining parameters involved in the process and to understand the effects of microwave on the oil palm mesocarp. Therefore, this work focuses on the drying behaviour, changes in surface structure and shrinkage of the oil palm mesocarp after microwave pre-treatment. The thermal stability of raw mesocarp was also examined to determine its thermal behaviour during heating process.

2. Materials and methods

2.1 Materials

Mesocarp was extracted from a fresh oil palm fruits (*Elaeis guineensis)* obtained from United Palm Oil Sdn Bhd, Pulau Pinang, Malaysia. The mesocarp was sliced in rectangular shape with initial dimensions of 18 mm height, 14 mm width and 2.5 mm thick. A 2,455 MHz programmable microwave (CEM's Microwave Assisted Reaction System 6) was used in this study where materials were placed and dried at a fixed plate in the configured microwave environment.

2.2 Determination of thermal properties of mesocarp

Thermogravimetric analysis (TGA) was performed to study the decomposition and thermal stability characteristics of the raw mesocarp. TGA analysis was carried out using Perkin Elmer STA 6000 simultaneous thermal analyser. 20 mg of the samples were placed in a platinum crucible. The experiments were carried out in a nitrogen atmosphere at 20 ml min^{-1}, with a constant heating rate at 20 °C min^{-1} from room temperature to 900 °C.

2.3 Microwave drying procedure

Various microwave power level (200 W, 150 W, 100 W and 50 W) were investigated on the rectangular sliced mesocarp. Sample was placed onto a glass petri dish (60 mm diameter with 15 mm height) and located at the centre of the microwave cavity throughout the microwave treatment. Moisture loss of the sample was measured periodically by weighing the dish on digital electronic balance. Volume of the rectangular sliced mesocarp was obtained based on the dimensions measured with a vernier caliper. The sample was assumed to achieve equilibrium when it reached a constant weight.

Moisture content at any drying time (X_t) determined according to Eq. (1) were obtained from the sample weight; initial sample weight (W_o), sample weight at any drying time (W_t) and equilibrium sample weight (W_f).

$$X_t = \frac{W_t - W_f}{W_o - W_f} \quad (1)$$

Shrinkage of oil palm mesocarp, S, was calculated according to Eq. (2)

$$S = \frac{V}{V_0} \quad (2)$$

where V and V_o are the volume of the mesocarp before and after microwave pre-treatment respectively.

2.4 Microscopic analysis of dried sample

The structure of the dried mesocarp slices at 100 W and 200 W for two minutes was examined using a scanning electron microscope (SEM) (TM3000 Tabletop Microscope). Each of the samples was mounted on a stud using double-sided adhesive carbon tabs, and coated in Quorum SC7620 sputter coater. Accelerating voltage of 15 kV with magnification of 500x was used to take the SEM images.

3. Results and discussion

3.1 Thermal analysis of mesocarp

TGA analysis was conducted to study the decomposition and thermal stability of raw mesocarp. The initial and final degradation temperatures for the mesocarp were measured in temperature ranged from 30 °C to 900 °C at a rate of 20 °C min^{-1} in nitrogen gas. Figure 1 show the both of the TGA curve, which shows the weight of the sample losses as a function of temperature, and its derivative weight curve to illustrate the mass loss rate. The curve shows three degradation steps and thermal stability up to 240 °C. As reported by Nabinejad et al. (2015), natural fibres generally decompose in three main stages, which attribute by the moisture evaporation and the lignocellulose decompositions. Table 1 shows the stages of weight loss of mesocarp. The first reaction stage happened from the room temperature to 245 °C, and the weight loss of the mesocarp determined at this stage is 1.15 %. At this stage, the weight loss was due to moisture evaporation in the sample (Norul Izani et al., 2013). A massive thermal degradation due to the decomposition of lignocellulose in the sample is observed when at the temperature causes a maximum rate of weight loss. The second stage went from 245 °C to 410 °C and showed a mass loss of 47.88 % corresponded to the decomposition of lignin from 245 °C to 255 °C and hemicellulose from 255 °C to 410 °C. The third stage went from 410 °C to 500 °C with a mass loss of 72.86 % corresponded to the decomposition of cellulose. As reported by Nabinejad et al. (2015), decomposition of lignin decomposed after end of the cellulose decomposition. Decomposition of lignin was then started from 500 °C to 815 °C. The decomposition of raw mesocarp ended at around 815 °C with a weight loss of 95.39 %. This indicates that the decomposition of the oil palm mesocarp starts at temperature above 245 °C. However, the highest experimental temperature of the mesocarp was recorded at 68 °C during the pre-treatment. Thus, weight loss of the mesocarp throughout the heating time is due to moisture evaporation.

3.2 Effects of microwave drying on the moisture content of mesocarp

Table 2 presents a comparison of the drying time needed for oil palm mesocarp to achieve 10 % moisture content at various microwave power. 26 % of the moisture content was determined in the raw mesocarp samples. From the table, longer drying time required at lower microwave power level. At 200 W, only two minutes of microwave treatment is needed to reach moisture content below 10 %, whereas the same amount of moisture content could be reached after 4 min, 10 min and 35 min for microwave power level of 150 W, 100 W and 50 W, respectively.

Table 1: Analysis of mesocarp weight loss in three stage with its chemical constituents

Stage 1		Stage 2		Stage 3		Stage 4	
Moisture evaporation		Lignin and hemicellulose decomposition		Cellulose decomposition		Lignin decomposition	
Temperature (°C)	Weight loss (%)	Temperature (°C)	Weight loss (%)	Temperature (°C)	Weight loss (%)	Temperature (°C)	Weight loss (%)
30 – 245	1.15	245 - 410	46.73	410 – 500	24.98	500 - 815	22.53

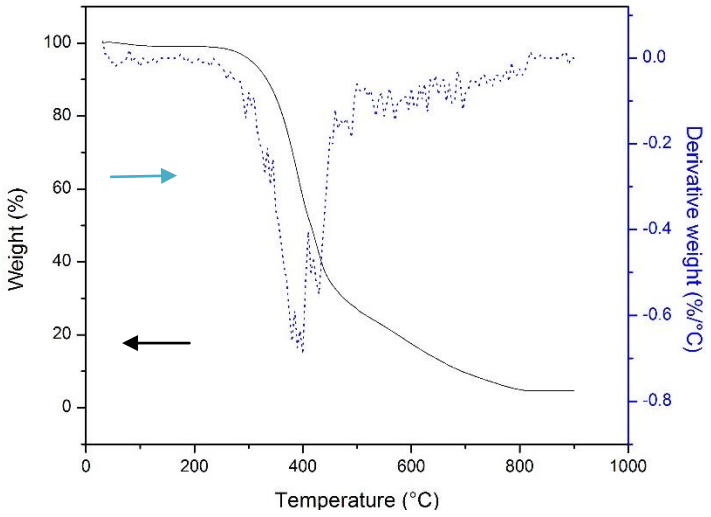

Figure 1: TGA analysis of raw mesocarp

Table 2: Drying time required to dry oil palm mesocarp to reach a moisture content below 10 %

Microwave power level (W)	Heating time on oil palm mesocarp to reach a moisture content below 10 % (min)
200	2
150	4
100	10
50	35

The variation of moisture content of the mesocarp dried at different microwave power density is depicted in Figure 2. Similar trend has been observed for microwave treated citrus foods (Ghanem et al., 2012) potato (Maskan, 2001), and honeysuckle berries (Zheng et al., 2013). The moisture content of the mesocarp at the same drying time decreased when a higher microwave power was applied. Microwave power affects the rate of drying of the mesocarp during microwave drying. The moisture content of the mesocarp was determined to be 0.21 kg/kg after 1 minute at 100 W. However, the moisture content of the mesocarp was below 0.16 kg/kg d.b. after same drying time at 200 W. This result indicated that rapid mass transfer occurred at a higher microwave power level because more heat is generated in the sample. However, as reported by Izli and Isik (2015), high microwave exposure will result in the damage of materials' microstructure which affected the quality of food. Therefore, investigation of microwave drying effects on the mesocarp microstructure will be reported in the following section.

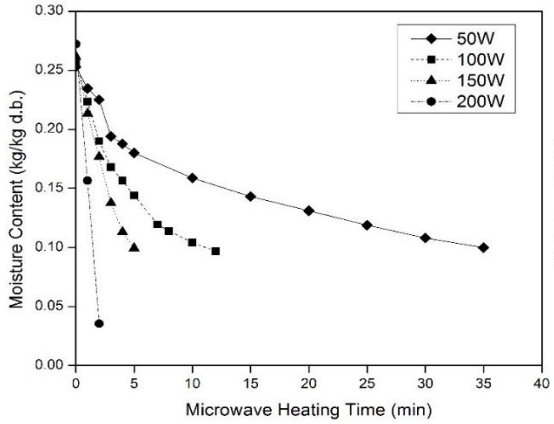

Figure 2: Effect of microwave power density on moisture content of mesocarp

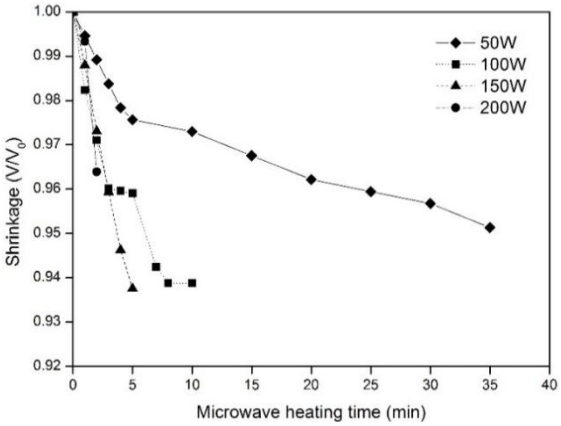

Figure 3: Influence of microwave power levels on volume shrinkage of oil palm mesocarp

3.3 Effects of microwave drying on the shrinkage of mesocarp

Shrinkage happened throughout the pre-treatment and it was calculated according to Eq. (2). Figure 3 shows the effect of microwave powers of 50 – 200 W on the study of volumetric shrinkage of the mesocarp. The volume reduction of the mesocarp was about 3.6 – 6.2 % when the heated mesocarp achieved 10 % moisture content. The shrinkage of the dried mesocarp is mainly due to moisture evaporation within the mesocarp. A lower microwave power leads to lesser microwave energy transmitted into the mesocarp. Thus, this explains why a longer time is required for mesocarp subjected at a lower microwave power level to reach the shrinkage effect. The shrinkage exhibiting an almost linearly behaviour correlated with their moisture content. Similar behaviour had been observed on other fruits e.g. kiwi (Maskan, 2001), potato (Mulet et al., 2000) and pears (Guiné et al., 2006).

3.4 Effects of microwave drying on the microstructure of mesocarp

In this study, the sliced mesocarp was microwave-dried at a microwave power of 100 W and 200 W for two minutes. Two minutes of microwave pre-treatment were selected because it provides an improved quality of the oil palm fruits yet capable to loosen the nut from the mesocarp (Cheng et al., 2011). In addition, two minutes of microwave treatment at 200 W is required to achieve 10 % moisture content in the mesocarp according to Table 2. The effects of microwave drying on the structure of the mesocarp were observed under SEM as shown in Figure 4. The cell structure are larger and further apart when the mesocarp slices were subjected to microwave drying at 200 W (Figure 4c) than those treated at 100 W (Figure 4b) comparing to the raw mesocarp (Figure 4a). The SEM micrographs represent the structural shrinkage during the drying process. Figure 4 concludes that increasing the microwave power level does not have a significant effect on destruction of the physical structure of the mesocarp.

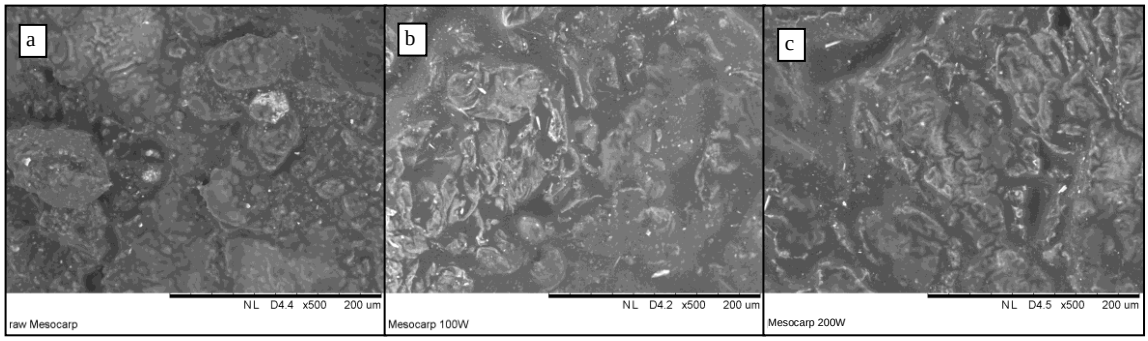

Figure 4: SEM micrographs of (a) raw mesocarp and that subjected to (b) 100 W and (c) 200 W

4. Conclusions

The thermal stability of the raw mesocarp was investigated. TGA analysis showed that the fresh mesocarp starts to decompose at 245 °C. In the microwave experiments, the highest temperature recorded in the mesocarp was only 68 °C. Thus, it can be concluded that the weight loss of the mesocarp during the microwave experiments was due to moisture evaporation. Besides, the morphology structure, the drying and the shrinkage behaviour of mesocarp were examined after subjected to microwave pre-treatment in this research. The drying time required to reduce the moisture content of the mesocarp from 26 % to 10 % was found to be ranging from 2 – 35 min using microwave power of 50 – 200 W. Under these conditions, the volume reductions of the mesocarp were found to be between 3.6 – 6.2 %. The magnitude of microwave power does not have significant effect on the surface microstructure of the mesocarp.

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