

Comparative microstructure study of oil palm fruit bunch fibre, mesocarp and kernels after microwave pre-treatment

Jessie S.L. Chang¹, Y.S. Chan^{2,*}, M.C. Law¹, C.P. Leo³

¹ Department of Mechanical Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009, Miri, Sarawak, Malaysia

² Department of Chemical Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009, Miri, Sarawak, Malaysia

³ School of Chemical Engineering, Engineering Campus, Universiti Sains Malaysia, Seri Ampangan, 14300 Nibong Tebal, S.P.S. Pulau Pinang, Malaysia.

*Email: chanyensan@curtin.edu.my

Abstract. The implementation of microwave technology in palm oil processing offers numerous advantages; besides elimination of polluted palm oil mill effluent, it also reduces energy consumption, processing time and space. However, microwave exposure could damage a material's microstructure which affected the quality of fruit that can be related to its physical structure including the texture and appearance. In this work, empty fruit bunches, mesocarp and kernel was microwave dried and their respective microstructures were examined. The microwave pretreatments were conducted at 100W and 200W and the microstructure investigation of both treated and untreated samples were evaluated using scanning electron microscope. The micrographs demonstrated that microwave does not significantly influence kernel and mesocarp but noticeable change was found on the empty fruit bunches where the sizes of the granular starch were reduced and a small portion of the silica bodies were disrupted. From the experimental data, the microwave irradiation was shown to be efficiently applied on empty fruit bunches followed by mesocarp and kernel as significant weight loss and size reduction was observed after the microwave treatments. The current work showed that microwave treatment did not change the physical surfaces of samples but sample shrinkage is observed.

1. Introduction

Moisture is a major constituent in fresh food and it serves as a good microwave energy absorber. The moisture contains in the food greatly influences the amount of microwave absorption during heating due to the dipolar nature. In microwave field, dipole molecules orient themselves with the electric field of the microwave. This rotation leads to molecular friction and heat generation, which is known as the dielectric polarization [1].

During the microwave irradiation, energy is transport volumetrically to the food through interaction between microwaves, polar water molecules and charged ions in food. The absorption and the conversion of microwave energy to heat depends on the dielectric nature of the food. Dielectric constant and dielectric loss is a measurement of dielectric properties of a food, which predict the amount of electromagnetic energy coupled into food, and the ability of food to convert the coupled



energy into heat respectively [2-4]. At present, microwave drying has been widely used in fruits processing [3, 5, 6]. In comparison with conventional drying method, microwave gives higher thermal efficiency, better energy savings, shorter drying time, and lower risk of overheating [7]. Microwave pre-treatment of the fresh fruit bunch (FFB) and its fresh fruits have been studied extensively. Microwave pre-treatment is capable of providing a rapid sterilization process than the conventional process. Sterilization is a process which aims to promote detachment of fruits from FFB and also to inhibit the enzymatic activity of lipase in fruits. The conventional sterilization process requires a large amount of steam at 140 °C for 75 – 90 min and often results in production of polluting waste water, i.e., palm oil mill effluent (POME). The microwave pre-treatment which is a dry, clean and yet encourages fruits softening and promotes fruits detachment from FFB [8, 9] is a great option in replacing the conventional steam sterilization. Furthermore, the quality of palm and kernel oil yielded from a microwave treated oil palm fruits was found to be superior than the commercial crude palm oil such as low free fatty acid (FFA) attribute to reduce microbiological activity [8-10], longer storage duration [11], low moisture content and improved chemical quality [9, 12].

During the microwave drying process, moisture content from food is removed at the temperature below boiling point. The drying process not only affects the moisture content of the food, but also changes its physical, mechanical, and chemical properties [13], such as reduction in dimensions [14], increment in bulk density [15] and decrement in mechanical strength [15, 16], and changes in color [16, 17]. In microwave drying process, Izli and Isik [18] reported that high microwave exposure could damage the materials' microstructure which affected the quality of fruit. Moreover, the quality of dried fruits is dependent in changes or modification of its physical structure including the texture and appearance. Dimension of the texture and appearance of several food grains and mineral in SEM images have been measured [19, 20] and the analysis of the geometric dimensions, morphological features and orientation of components can be identified [21].

Numerous literatures on the effects of the microwave treatment on the quality, chemical and physical properties of the EFB and the oil palm fruits have been conducted. Nevertheless there is limited work on the influences of microwave drying process on its microstructure particularly on the raw EFB fibers, mesocarp and kernel. As such, this comparative microstructures studies on the morphology of EFB, mesocarp and kernel aim to reveal the influences of microwave irradiation on their microstructures.

2. Materials and methods

2.1. Material preparation

The fresh palm fruit bunches (*Elaeis guineensis*) were obtained from United Palm Oil Sdn Bhd, Pulau Pinang, a local oil palm mill in Nibong Tebal, Penang, Malaysia. The unprocessed empty fruit bunches (EFB) were collected after the palm fruits detachment from the fruit bunches. The EFB were cut into 21mm x 13mm x 5.5mm slides by using a cutter and a hacksaw (Stanley 15-265). Palm fruits were cut to obtain its mesocarp and kernel. Mesocarp samples with dimensions of 20mm x 10mm x 4mm and kernel samples with mean diameter of 12mm were used in the experiments. The samples were stored in fridge prior pre-treatment process.

2.2. Microwave treatment

Samples were treated at 100W and 200W for two minutes in 2455MHz microwave (CEM's Microwave Assisted Reaction System 6). Microwave treatment duration of two minutes was chosen as better quality of kernel oil and palm oil from oil palm fruits were obtained [9] whereas 100W and 200 W microwave power selection was due to the limitation of domestic microwave. The weight and size of the samples before and after treatment were measured using an electronic balance (AA-160 Denmer) and a vernier caliper. Samples then were grinded and placed in a desiccator before SEM analysis.

2.3. Scanning electron microscope (SEM) analysis

The morphological structures of the raw and pre-treated samples were observed through a scanning electron microscope (TM3000 Tabletop Microscope). Each sample was mounted on a stub using double-sided adhesive carbon tabs before coated with gold in a sputter coater (Quorum SC7620) in order to prevent charging of the specimen with electron beam. Images were taken at an accelerating voltage of 15kV with magnifications of 500x to 5000x. Particle size analysis was conducted using the ImageJ.

3. Results and discussion

3.1. Weight loss and size reduction

Initial moisture content and the dielectric properties of EFB, mesocarp and kernel were shown in Table 1. It showed that microwave pre-treatment has a greater effect on weight loss in EFB followed by the mesocarp and the kernel [22]. As the microwave effect contributes to the loss of moisture of the samples is due to the dielectric properties, higher dielectric constant of EFB indicates higher ability in energy storage. Hence, a higher dielectric loss of EFB leads to greater microwave energy dissipation. Thus, more heat is generated and the evaporation of the moisture content within the EFB is enhanced [4]. According to Table 1, lower dielectric constant of the mesocarp and kernel lead to lower heat absorption.

Table 1. Properties of raw EFB, mesocarp fiber and kernel

| | Initial Moisture Content (kg/kg) | Dielectric constant at 2.45GHz, ϵ' | Dielectric loss 2.45GHz, ϵ'' |
|-----------------------|-------------------------------------|--|--|
| EFB [23] | 0.69 | 57.4 | 18.6 |
| Mesocarp pulp [8, 24] | 0.37 | 11.5 | 4.2 |
| Kernel [8, 25] | 0.23 | 11.7 | 5.8 |

During microwave pre-treatment, weight losses of the samples were observed due to the lost of moisture within the samples and later led to sample shrinkage. Weight loss and size reduction of the samples after microwave pre-treatment were shown in Table 2.

Table 2. Percentage of weight loss and size reduction of the EFB, mesocarp and kernel after microwave pre-treatment

| Sample | Weight loss, % | | Size reduction, % | |
|----------|----------------|------|-------------------|------|
| | 100W | 200W | 100W | 200W |
| EFB | 11.4 | 26.8 | 22.5 | 34.6 |
| Mesocarp | 6.0 | 18.6 | 2.6 | 2.9 |
| Kernel | 1.5 | 3.0 | 0.6 | 1.2 |

The percentage of sample weight loss (W) and size reduction (S) are defined as:

$$\%W = \frac{W_i - W_x}{W_i} \quad (1)$$

$$\%S = \frac{V_i - V_x}{V_i} \quad (2)$$

where W_i and W_x are the initial and final weight of the sample and V_i and V_x are the initial volume of the sample.

The weight lost of the EFB, mesocarp and kernel were 11.4%, 6.0% and 1.5% respectively after expose to 100W of microwave power while 26.8%, 18.6% and 6.0% respectively after 200 W. A higher microwave power exposure leads to greater dielectric heating effect on the sample.

Moreover, decreased in the size of EFB, mesocarp and kernel samples were also observed after pre-treatment. At the same exposure time and power, the size reduction of the EFB is much greater as compared to mesocarp and kernel. Size reduction occurred because the sample is unable to support its own weight and hence collapses in the absence of moisture [26]. As amount of moisture lost in the sample is directly proportional to its weight lost [22], more moisture loss in the EFB results in a higher size reduction in comparison with the kernel and mesocarp. The size of treated EFB, mesocarp and kernel were reduced by 22.5 - 34.6 %, 2.6 - 2.9 % and 0.6 - 1.2 % respectively as shown in Table 2.

EFB contain high composition of volatiles components; components which formed into gas phases during heating process. The high compositions of flammable volatile components in the EFB had caused it to burn and ignite at a lower temperature [27]. It was also noticed that raw EFB was burnt when exposed to microwave power level of more than 200W. This is possibly due to excessive heat generated within the EFB which led to overheating.

3.2. Changes of microstructure of EFB

Figure 1 shows the surface structures of the raw and treated EFB under 1000x and 5000x magnifications. It is noticed that the raw EFB having a similar surface structure as reported by other researchers [28-32]. In the micrographs, pores that are round in shape were found on the fiber strand. The presence of pores in the raw and treated EFB shows that EFB is a fibrous material [24]. In addition, the granular starch was also found in the fiber strand.

From micrograph, it is shown that the round-shaped granular starch remains deposited after the microwave treatment, but the size of granular starch was reduced after the treatment (Table 3). The size of granular starch was reduced from 0.115 mm to 0.009 mm and 0.006 mm after exposure of 100 W and 200 W respectively. Smaller size of the granular starch is desirable as it could facilitate the removal of starch. The removal of starch could increase the surface area of the fibre for biomass treatment [30, 33]. In the current sterilization process, starch presents in fruit and EFB is removed through hydrolysis, where it is broken down by supplied wet steam [34]. Hence, it is believed that microwave treatment could be used to replace the conventional steam sterilization which produces undesired palm oil mill effluents.

The raw EFB had a rough surface with a great number of spiky and round-shaped globular protrusions at the fiber strands. Previous studies identified the globular protrusions as silica bodies [30]. The attached silica bodies in circular crater were distributed uniformly along the surface of the strand. Silica bodies were observed to remain attached at the surface after the microwave treatment. Silica bodies are undesirable in industrial processes as they are inert to most chemicals. In addition, they are hard and could only be removed by alkali treatment or by mechanically or at high temperature [30]. Figure 1 showed that a small portion of the silica bodies of EFB treated at 200W was disrupted. Table 3 shows the diameter of the silica body, and circular crater before and after microwave drying process. The drying process has increased the diameter of circular crater from 0.112 mm to 0.134 mm and 0.171 mm after exposed to microwave treatment for two minutes. Increased in the diameter of circular crater could facilitate the removal of silica bodies from the crater and hence result in better

fiber-matrix interfacial adhesion of the EFB for further composite fabrication. As shown in Figure 1(b) and 1(c), microwave treatment has the potential to remove and disrupt the silica bodies. Despite on the reduction of the circular crater, the diameter of the silica body remains constant after exposed to microwave treatment.

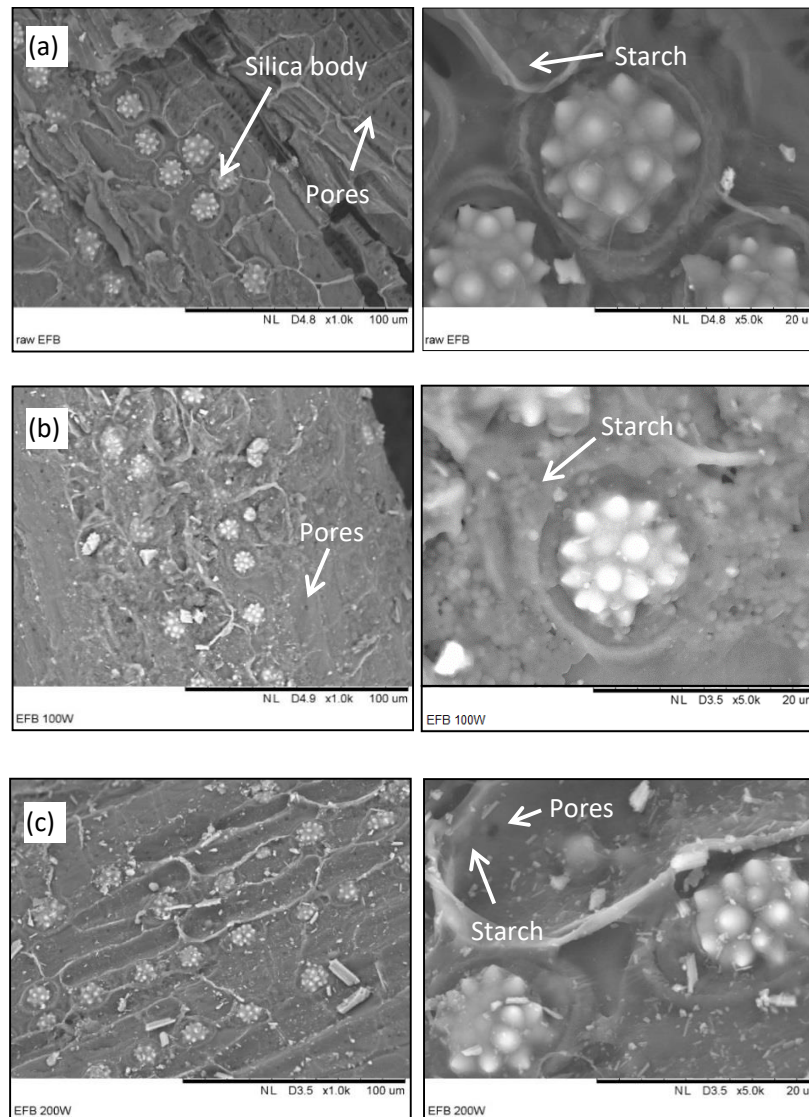


Figure 1. SEM micrographs at 1000x and 5000x magnifications of (a) raw and microwave treated EFB samples at a power level of (b) 100W and (c) 200W.

Table 3. Diameter of the silica bodies, circular crater and granular starch in the raw and microwave treated EFB.

| Sample | Diameter of granular starch (mm) | Diameter of circular crater (mm) | Diameter of the silica body in the circular crater (mm) |
|---------------------|----------------------------------|----------------------------------|---|
| Raw EFB | 0.115 | 0.112 | 0.088 |
| Treated EFB at 100W | 0.009 | 0.134 | 0.087 |
| Treated EFB at 200W | 0.006 | 0.171 | 0.089 |

3.3. Changes in microstructure of kernel

Figure 2 shows the surface structure of raw and treated palm kernel. The surface structure of raw and treated kernel under a magnification of 1500x showed similar observations by Zaidul et al. [35]. It has clearly showed the oil glands and cell structures on the surface of kernel. The oil glands are enveloped by cell structure. There is no significant change on the oil gland and cell structure of the treated kernels (Figure 2b and 2c) as compared to the raw kernel (Figure 2a). However, it noticed that the surface of the treated kernel (Figure 2b and 2c) shrunk due to moisture lost. The shrinkage, however, had increased the width of cell structure, as shown in Table 4. The width of cell structure of the raw kernel had increased from 0.145 mm to 0.263 mm and 0.388 mm after microwave pre-treatment at 100 W and 200 W respectively. However, these have no impact on the appearance of the oil gland on the surface. Furthermore, oil were found deposited on the surface of the treated kernel, and this had led to the observed increased of the cell structure.

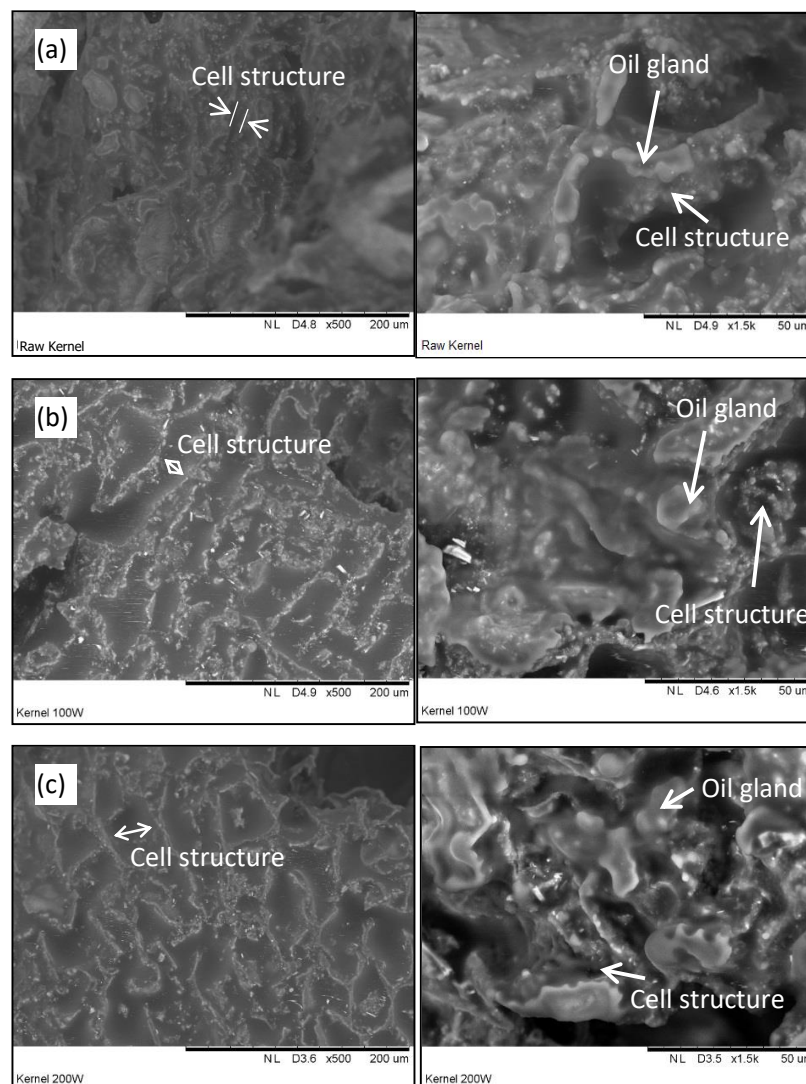


Figure 2. SEM micrographs at 500x and 1500x magnifications of (a) raw and microwave treated kernel at power level of (b) 100W and (c) 200W.

Table 4. Width of cell structure of the raw and microwave treated kernel

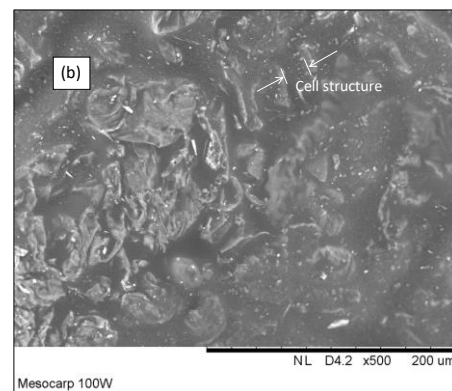
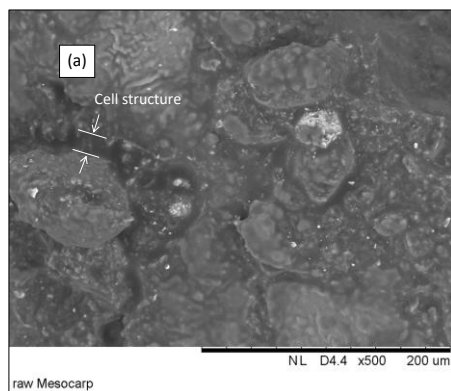
| Sample | Width of cell structure (mm) |
|------------------------|------------------------------|
| Raw kernel | 0.145 |
| Treated kernel at 100W | 0.263 |
| Treated kernel at 200W | 0.388 |

3.4. Changes in the microstructure of mesocarps

The microstructures of the fresh and treated mesocarps under a 500x magnification are shown in Figure 3. The morphology of the mesocarp pulp shows a wrinkled shaped texture. Similar morphology were observed by Ho et al. [36]. Oil glands were found deposited on the surface.

No significant changes on the oil gland were also observed in treated mesocarp as compared with the raw mesocarp. However, the moisture lost after the microwave treatment resulted in shrinkage to the mesocarp is noticeable. The shrinkage, however, increases the width of cell structure of the mesocarp which as shown in Table 5. The width of cell structure of the raw mesocarp had increased from 0.128 mm to 0.143 mm and 0.1698 mm after microwave exposure at 100 W and 200 W respectively. Surface of the treated mesocarp too was found deposited with oil, as a result of microwave treatment. Yielded oil had led to the observed increased of the cell structure.

Figure 3: SEM micrographs at x500 magnifications of (a) raw and microwave treated mesocarp at power level of (b) 100W and (c) 200W.



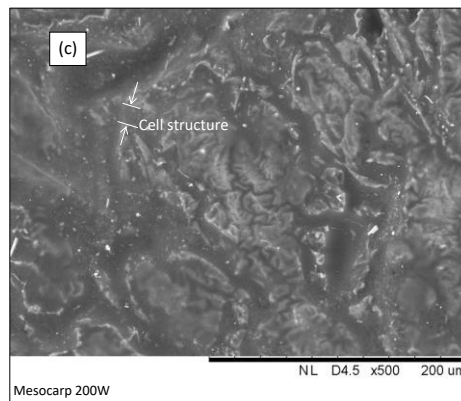


Figure 3. SEM micrographs at 500x magnification of (a) raw and microwave treated mesocarp at a power level of (b) 100W and (c) 200W.

Table 5. Width of cell structure of the raw and microwave heated mesocarp.

| Sample | Width of cell structure (mm) |
|--------------------------|------------------------------|
| Raw mesocarp | 0.128 |
| Treated mesocarp at 100W | 0.143 |
| Treated mesocarp at 200W | 0.169 |

4. Conclusion

In spite of microwave irradiation method gives a faster process time and reduces energy consumptions, microwave exposure could damage microstructure of fruit and subsequently affect the fruit's quality. However, limited works report on their texture and appearance after microwave drying process. SEM has shown the appearance change of the microwave treated samples as compared to those before treatment. The following conclusions can be made from the current study:

- High moisture content and high dielectric properties result in a high efficiency of microwave drying treatment. EFB experiences a significant effect on weight loss and size reduction, followed by the mesocarp and kernel. The weights were reduced by 11.4 - 26.8%, 6.0 - 18.6% and 1.5 - 3.0% for treated EFB, mesocarp and kernel respectively. Meanwhile, the sizes reduction of 22.5 - 34.6%, 2.6 - 2.9% and 0.6 - 1.2% was observed on the treated EFB, mesocarp and kernel respectively.
- SEM micrographs confirmed that surface of EFB had visible changes after the microwave drying process but had no significant effect on the kernel and mesocarp. In comparison to the raw samples, insignificant changes of the physical structure on the dried kernel and mesocarp had ensure that the quality has a minimal deterioration [37]. The oil glands deposited on the surface of treated kernels and mesocarps were not influenced by the microwave treatment. However, the microwave treatment on EFB had reduced the size of granular starch, increased the crater surrounded silica bodies and disrupted the silica bodies, as these are beneficial for the further EFB biomass treatment.
- Effects of microwave power on the drying process were investigated on the EFB, mesocarp and kernel. Despite greater reductions of the weight and size of the samples after treated at higher microwave power, the morphologies of the EFB, mesocarp and kernel were only slightly different.

In this study, domestic microwave oven at 2450MHz is used as the main sources, this leads to difficulties in scaling up the results to industrial-scale application. Further studies should use larger microwave systems with higher frequency based on industrial level microwave heating equipment.

XRD analysis is also recommended in future to provide quantitative support on the identification of silica body.

5. Acknowledgement

This work was supported by the Fundamental Research Grant Scheme (FRGS/2/2014/TK06/CURTIN/03/1). The authors acknowledge United Palm Oil Sdn Bhd, Pulau Pinang, Malaysia for providing fresh fruit bunch and Curtin Sarawak for financial support.

References

- [1] Anwar J, Shafique U, Waheed-uz-Zamana, Rehman R, Salman M, Dar A, Anzano JM, Ashraf U, Ashraf S. Microwave chemistry: Effect of ions on dielectric heating in microwave ovens. *Arabian J. Chem.* 2015;**8**:100-4.
- [2] Mudgett RE. Microwave properties and heating characteristics of foods. *Food Technology.* 1986;**40**:84-93.
- [3] Umesh Hebbar H, Rastogi NK. Chapter 12 - microwave heating of fluid foods. In: Valdramidis PJCKTP, editor. Novel thermal and non-thermal technologies for fluid foods. San Diego: Academic Press; 2012. p. 369-409.
- [4] Magee TRA, McMinn WAM, Farrell G, Topley L, Al-Degs YS, Walker GM, Khraisheh M. Moisture and temperature dependence of the dielectric properties of pharmaceutical powders. *J. Therm. Anal. Calorim.* 2013;**111**:2157-64.
- [5] Law CL, Chen HHH, Mujumdar AS. Food technologies: Drying. In: Motarjemi Y, editor. Encyclopedia of food safety. Waltham: Academic Press; 2014. p. 156-67.
- [6] Sabarez HT. 4 - modelling of drying processes for food materials. In: Fryer SBKJ, editor. Modeling food processing operations: Woodhead Publishing; 2015. p. 95-127.
- [7] Atong D, Ratanadecho P, Vongpradubchai S. Drying of a slip casting for tableware product using microwave continuous belt dryer. *Drying Technol.* 2006;**24**(5):589-94.
- [8] Chow MC, Ma AN. Processing of fresh palm fruits using microwaves. *J. Microwave Power Electromagn. Energy.* 2007;**40**(3):165-73.
- [9] Cheng SF, Mohd NL, Chuah CH. Microwave pretreatment: A clean and dry method for palm oil production. *Ind. Crops. Prod.* 2011;**34**(1):967-71.
- [10] Nokkaew R, Punsuvon V. Sterilization of oil palm fruits by microwave heating for replacing steam treatment in palm oil mill process. *Advanced Materials Research.* 2014;**1025-1026**:470-5.
- [11] Umudee I, Chongcheawchamnan M, Kiatweerasakul M, Tongurai C. Sterilization of oil palm fresh fruit using microwave technique. *International Journal of Chemical Engineering and Applications.* 2013;**4**(3):111-3.
- [12] Sukaribin N, Khalid K. Effectiveness of sterilisation of oil palm bunch using microwave technology. *Ind. Crops. Prod.* 2009;**30**(2):179-83.
- [13] Barbosa-Canovas GV, Vega-Mercado H. Dehydration of foods. New York, United States of America 1996.
- [14] Li H, Pordesimo LO, Igathinathane C, Vinyard B. Physical property effects on drying of chile peppers. *Int. J. Food Prop.* 2009;**12**:316-30.
- [15] Karababa E, Coskuner Y. Moisture dependent physical properties of dry sweet corn kernels. *Int. J. Food Prop.* 2007;**10**:549-60.
- [16] Abasi S, Minaei S. Effect of drying temperature on mechanical properties of dried corn. *Drying Technol.* 2014;**32**:774-80.
- [17] Guiné RPF. Influence of drying method on some physical and chemical properties of pears. *International Journal of Fruit Science.* 2011;**11**:245-55.
- [18] Izli N, Isik E. Color and microstructure properties of tomatoes dried by microwave, convective, and microwave-convective methods. *Int. J. Food Prop.* 2015;**18**(2):241-9.

- [19] Igathinathane C, Pordesimo LO, Batchelor WD. Major orthogonal dimensions measurement of food grains by machine vision using imagej. *Food Res Int.* 2009;**42**:76-84.
- [20] Pollastri S, Gualtieri AF, Gualtieri ML, Hanuskova M, Cavallo A, Gaudino G. The zeta potential of mineral fibres. *J Hazard. Mater.* 2014;**276**:469-79.
- [21] Mur A, Purcell C, Soong Y, Crandall D, McLendon TR, Haljasma IV, Warzinski R, Kutchko B, Kennedy S, Harbert W. Integration of core sample velocity measurements into a 4d seismic survey and analysis of SEM and CT images to obtain pore scale properties. *Energy Procedia.* 2011;**4**:3676-83.
- [22] Dincer I. Moisture loss from wood products during drying—part ii: Surface moisture content distributions. *Energy Sources.* 2007;**20**:77-83.
- [23] Omar R, Idris A, Yunus R, Khalid K, Aida Isma MI. Characterization of empty fruit bunch for microwave-assisted pyrolysis. *Fuel.* 2011;**90**(4):1536-44.
- [24] Sabil KM, Aziz MA, Lal B, Uemura Y. Effects of torrefaction on the physiochemical properties of oil palm empty fruit bunches, mesocarp fiber and kernel shell. *Biomass Bioenergy.* 2013;**56**:351-60.
- [25] Kok S, Ong-Abdullah M, Ee GC, Namasivayam P. Comparison of nutrient composition in kernel of tenera and clonal materials of oil palm (*elaeis guineensis jacq.*). *Food Chem.* 2011;**129**:1343-7.
- [26] Witrowa-Rajchert D, Rząca M. Effect of drying method on the microstructure and physical properties of dried apples. *Drying Technol.* 2009;**27**(7-8):903-9.
- [27] Abdullah N, Sulaiman F. The properties of the washed empty fruit bunches of oil palm. *Journal of Physical Science.* 2013;**24**(2):117-37.
- [28] Norul Izani MA, Paridah MT, Anwar UMK, Mohd Nor MY, H'ng PS. Effects of fiber treatment on morphology, tensile and thermogravimetric analysis of oil palm empty fruit bunches fibers. *Composites Part B* 2013;**45**(1):1251-7.
- [29] Nasri NS, Hamza UD, Abdulkadir A, Ismail SN, Ahmed MM, editors. Utilization of sustainable palm empty fruit bunch sorbents for carbon dioxide capture. 6th International Conference on Process Systems Engineering (PSE ASIA); 2013; Kuala Lumpur.
- [30] Law KN, Daud WRW, Ghazali A. Morphological and chemical nature of fiber strands of oil palm empty-fruit bunch (opefb). *BioResources.* 2007;**2**(3):351-62.
- [31] Baharuddin AS, Sulaiman A, Kim DH, Mokhtar MN, Hassan MA, Wakisaka M, Shirai Y, Nishida H. Selective component degradation of oil palm empty fruit bunches (opefb) using high-pressure steam. *Biomass Bioenergy.* 2013;**55**:268-75.
- [32] Shinoj S, Visvanathan R, Panigrahi S, Kochubabu M. Oil palm fiber (opf) and its composites: A review. *Ind. Crops Prod.* 2011;**33**(1):7-22.
- [33] Zheng Y, Pan Z, Zhang R. Overview of biomass pretreatment for cellulosic ethanol production *Int. J. Agric Biol Eng.* 2009;**2**(3):51-67.
- [34] Pradeepkumar T, Jyothibhaskar BS, Satheesan KN. Management of horticultural crops. Peter KV, editor. New Delhi: New India Publishing; 2008.
- [35] Zaidul ISM, Norulaini NAN, Omar AKM, Sato Y, Smith Jr RL. Separation of palm kernel oil from palm kernel with supercritical carbon dioxide using pressure swing technique. *J. Food Eng.* 2007;**81**(2):419-28.
- [36] Ho LS, Nair A, Yusof HM, Kulaveerasingam H, Jangi MS. Morphometry of lipid bodies in embryo, kernel and mesocarp of oil palm: Its relationship to yield. *American Journal of Plant Sciences.* 2014;**5**:1163-73.
- [37] Kong F, Singh RP. 2 - chemical deterioration and physical instability of foods and beverages. In: Kilcast D, Subramaniam P, editors. Food and beverage stability and shelf life: Woodhead Publishing; 2011. p. 29-62.