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Influence of Microwave Drying on the Properties of *Moringa oleifera* Leaves

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Moringa oleifera leaves were dried in a domestic microwave oven to investigate the influence of microwave power levels on rate of drying, drying time, the quality of the dried product based on their colour, protein, and iron content as well as the energy consumption. Four different microwave power levels varying from 300 to 1,000 W were selected in the experiments. Drying time increased significantly with the decrease in microwave output power. At 1,000, 800, 500 and 300 W the drying time were 6, 8, 10 and 20 min. The initial drying rate was very fast at all power levels as the penetration of microwave power were applied throughout the leaves. All microwave power levels showed a drying rate in a decreasing trend as the falling rate was observed at the point when the moisture content (MC) started to reach below 5 %. Throughout the drying progression, the drop in the product moisture caused a decrease in the absorption of microwave power and leads to a fall in the drying rate. For the changes in the colour, there was a significant difference in the value for greenness (-a), but no notable differences were observed between the colour parameters of fresh and microwave-dried leaves for whiteness L value, yellowness b and hue angle. This indicates that drying under a microwave oven darken the leaves, yet the colour retained its original values similar to the fresh *M. oleifera* leaves. There was no significant difference in the value for protein but a significant difference in the value for iron contents of the fresh and microwave-dried leaves ($P<0.05$). The highest energy consumption was recorded at 1,000 W with 0.154 kWh and the lowest at 500 W with 0.117 kWh. Results from this experiment reveal a great alternative for the microwave oven method on *M. oleifera* leaves as a rapid drying method.

1. Introduction

Moringa oleifera is a plant that can be widely found in South, East, and West Africa, Latin America and tropical Asia country. This green plant had been intensively used for medicinal and food purposes in most country as it contains a balanced level of amino acids as well as high amounts of essential nutrients such as protein, calcium, carbohydrate, minerals and vitamins. The plant is used extensively for treatment for malnutrition as it provides low-cost nutrition and contain natural antioxidant properties (Feihrmann et al., 2017). Study by Alain Mune Mune (2016) has reported that the protein content in *M. oleifera* seeds and leaves are 33.53 % and 18.63 %. This abundance content of protein concentration and adequate amount of nutrients shows its potential in medicinal and food application. Study by Asante et al. (2014) found that six tablespoons full of *M. oleifera* leaf powder will provide the daily amount of calcium and iron needed throughout pregnancy and breastfeeding of a woman.

Drying is a crucial process to preserve the appearance, nutritional characteristics, and aroma of raw herbs as maximum as possible (Crivelli et al., 2002) while maintaining its shelf-life quality in the aspect of flavour, quality, and avoidance of microbial growth. Drying method is the initial processing steps in every food industry with the purpose of preserving its preferable qualities, lower storage volume and to extend their shelf life (Elzaawely and Tawata, 2011). Capecka et al., (2005) stated that, different drying methods may cause a significant difference in the composition of phytochemicals in a dried product. There are different methods used in previous studies for drying of *M. Oleifera* leaves such as shade drying (Anjorin et al., 2010), oven drying (Ali et al., 2014), freeze drying (Ali et al., 2017) and microwave drying (Ali et al., 2017). Microwave drying method had gain popularity

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among researcher as a drying mechanism for food, medicinal and herbs. This is because it produces a good quality of final products as well as able to shorten the drying time without degrading the quality of herbs (Arslan and Ozcan, 2010), while reducing the energy consumption and lowering operating costs. The previous study on the drying of *M. oleifera* leaves using microwave was done only for one power level Ali et al. (2017) while Yashaswini et al. (2021) investigated the nutritional composition and color change without taking to account the energy consumption. The objectives of this study were to (i) investigate the effect of microwave power levels (300, 500, 800 and 1,000 W) on the drying curve of *M. oleifera*; (ii) examine the changes in the colour, iron, and protein values of the sample after drying; and (iii) determine energy consumption for the drying of *M. oleifera* leaves by using microwave drying method.

2. Materials and Methods

2.1 Preparation of sample

Moringa Oleifera Lam. leaves were collected from Hadham Enterprise, Johor, Malaysia (Latitude 1.5530˚N, Longitude 103.6698˚E). The plant was recognized and authenticated taxonomically at the Forest Research Institute Malaysia (FRIM), Malaysia. The voucher specimen, PID 181220-14, was deposited in the department. *M. oleifera* leaves were washed using running water and cleaned with a cloth to remove dirt and water on the surface of the leaves.

2.2 Analysis of moisture content and drying of *Moringa oleifera* leaves

After no decent amount of water can be observed on the leaves, they were analysed to obtain its initial moisture content. Moisture content was determined using moisture analyser (Ohaus Halogen, Model MB25, USA). Microwave drying was performed using a 34 L domestic microwave oven (Sharp, Model R-774AST, Japan) by utmost output of 1,000 W at 2,450 MHz. The microwave size capacity was 519 x 315 x 442 mm^3 and the oven was installed with a glass turntable (315 mm diameter). 30 g of fresh leaves sample was placed in a round pan and placed on the glass turntable in the microwave. Four different microwave power levels (300, 500, 800 and 1,000 W) were investigated with triplicates. The drying was conducted until the moisture content (MC) of the leaves reached below 5 % (Geankoplis, 2003). Then the dried leaves were ground using an electric grinder (Waring Commercial Blender 8011S, Model HGB2WTS3, USA) and sieved using a stainless-steel sieve with 355 µm aperture. The dried leaves powder was kept in a sealed container and placed in a dry and dark cabinet for storage. The drying rate (DR) during drying experiments was calculated using the following Eq(1):

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (1)$$

where DR (Drying Rate (g water/ g Dry Matter/ min), M_t (moisture content at t (g water/g Dry Matter), M_{t+dt} (moisture content at t + dt (kg moisture/kg dry matter)) and dt (drying time (min)).

2.3 Colour analysis

Colour analysis was performed for the samples before and after drying by using a Konico Minolta Chroma CR-400 colour meter (Minolta Co., Osaka, Japan). A white surfaced tile of a standard calibration plate was used to calibrate the colour meter and set to CIE Standard Illuminant C. The measurement was programmed to fix at CIE L* a* b* colour space coordinates. Six random readings per sample were measured and the mean values of colour parameters (L*, a*, b*) were recorded (Ali et al., 2017). ΔE^*_{ab} was determined [Eq(2)] which indicates the size of the colour difference between two objects and hue angle, h_{ab} were measured from the values of a* and b* [Eq(3)] to describe the colour change during drying process:

$$\Delta E^*{}_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

$$Hue\ angle, h_{ab} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (3)$$

2.4 Protein and iron analysis

The protein and iron analysis of the dried leaves were analysed using the Association of Official Analytical Chemists (AOAC) method. For protein content the method used was AOAC 2001.11 while for iron content the method used was AOAC 999.11 and APHA 3120B.

2.5 Energy consumption measurement

Energy consumption of microwave oven was measured using a Plug in Energy Monitor Analyzer (UK P01, China) with 0.01 kWh precision. The energy consumption of the drying process was analysed once the moisture content (MC) reached below 5 % (Geankoplis, 2003).

2.6 Data analysis

All results were recorded as mean ± standard deviation (SD) for three replicates. The experiment was statistically analysed using Microsoft Excel statistical tools. T-test was calculated between the data with the value of $P < 0.05$ was considered as statistically significant.

3. Results and Discussion

3.1 Microwave drying curve

Figures 1a and b illustrate the moisture content (MC) and drying rate for *M. oleifera* leaves at different microwave power range from 300 to 1,000 W. The moisture content declined gradually from the early moisture content of 77.84 % as the drying time increased at all power levels (Figure 1a). The higher the microwave power, the shorter the drying time needed to reach the moisture content less than 5 %. The final moisture content of dried leaves at 300, 500, 800 and 1,000 W was around 5.01, 4.64, 3.00 and 2.91% and reached equilibrium moisture content at 20, 10, 8 and 6 min. This shows that, the lower the power level, the longer the drying time needed to reduce moisture content to less than 5 %. By reducing the moisture content to less than 5 % *M. oleifera* leaves will be able to retain its flavour and nutrition (Geankoplis, 2003) as well as the optimal condition for additional processing and storage (Ali et al., 2017). This result shows that moisture content was significantly influenced by microwave power level and drying time, as well as a time-power interaction. The biggest impact was displayed at the increase of power from 300 W to 500 W with the biggest moisture reduction and also at a significant drying time reduction. Similar pattern has also been reported by (Mujaffar and Bynoe, 2020) in drying of *Pimenta racemosa*.

As shown in Figure 1b, the initial drying rate was very high as the penetration of microwave power were applied to the leaves, more evaporation took place and more moisture was loss as high moisture diffusion occur (Mujaffar and Bynoe, 2020). As the drying time increased, a declining trend of drying rate was observed. At this stage, falling rate occurred as the MC started to reach below 5%. Similar behaviour of drying rate has been reported by previous researchers in using microwave drying for leafy sample materials such as *M. oleifera (*Potisate and Phoungchandang, 2015), coriander (Hihat et al., 2017), *Vaccinium meridionale* (Swartz) (Borba-Yepes et al., 2018) and West Indian Bay Leaves (Mujaffar and Bynoe, 2020).

Previous study on the drying of *M. oleifera* leaves using conventional oven drying by Ali et al. (2014) took about 8, 5.75 and 2 h at 40, 50 and 60°C to obtain 5 % MC; a much longer drying time compared to this study. This indicates that using microwave drying provides a promising alternative for drying of *M. oleifera* leaves at a significantly shorter drying time. Shorter drying time can be achieved because microwaves penetrate into the food and heat both sides, the outer surface and also inside the food which leads to faster drying process and enhanced quality of the end product (Contreras et al., 2008).

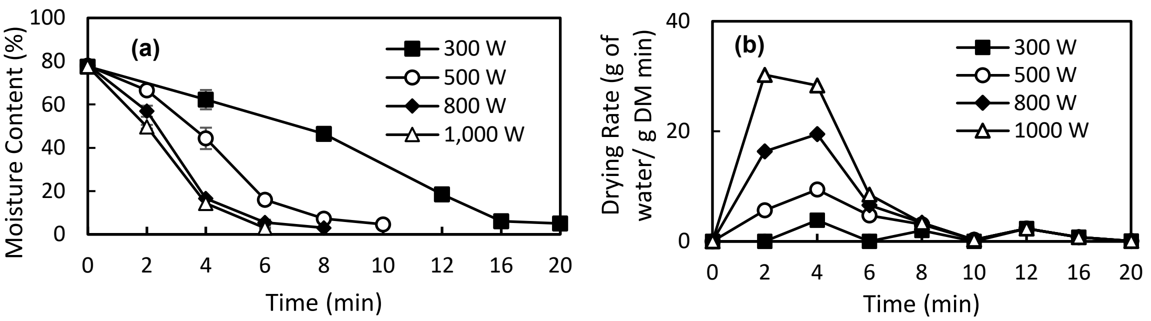


Figure 1: (a) Moisture content (b) Drying rate for microwave drying of M. oleifera leaves at different power levels

3.2 Colour measurements

Appearance of a dried leaves is a crucial indicator in terms of quality aspect to obtain an acceptance from the market for the final product. Table 1 shows the colour measurement of fresh and dried leaves for all four microwave power. The initial values of L*, a* and b* for fresh *M. oleifera* leaves was 46.18, -4.69 and 5.39. The lightness values L* decreased slightly as the drying power increase from 300 W to 500 W but slightly increase at 800 W to 1,000 W. There was no significant difference to the changes in L* values as the drying power increases. This slight changes in L* may resulted in the leaves appearance to become dark green. Study by Ali et al. (2014) reported that the differences in lightness value of dark green in *M. oleifera* leaves might probably be due to chlorophyll degradation. Similar effect has been reported by Rudra et al. (2008) where the L* value dropped after drying at all drying temperatures during oven drying.

Table 1: Effect of microwave output power on the colour of M. oleifera leaves

	FRESH	300 W	500 W	800 W	1,000 W
L*	46.18 ± 2.99^{a}	44.61 ± 0.20^{b}	43.42 ± 0.08^{c}	43.96 ± 0.63^{a}	44.80 ± 2.02^{a}
a*	-4.69 ± 0.28^{a}	-2.32 ± 0.25^{b}	-2.14 ± 0.76^{c}	-3.18 ± 0.97^{a,b,c,d}	-3.76 ± 0.31^{d}
b*	5.39 ± 1.01^{a}	4.62 ± 0.44^{a}	4.18 ± 0.26^{c}	4.90 ± 1.09^{a,b,c,d}	5.83 ± 0.50^{d}
Hue (°)	-0.8546	-1.1050	-1.0976	-0.9959	-0.9980
ΔE^*_{ab}		2.9457	3.9484	2.7286	1.7264

*Values are mean values from triplicates ± STDEV
*In a row with different superscript letters are significantly different (P<0.05)

The value of ΔE^*_{ab} obtained at 1,000 W has the smallest colour difference compared to the fresh leaves followed by 800 W, 300 W and 500 W. This indicated that the changes in colour values was minimal in higher microwave power as the drying duration was shorter and it is preferable in dried product (Ali et al., 2017). A similar trend was obtained by Potisate and Phoungchandang (2015) where the smallest ΔE^*_{ab} was obtained at 900 W. From the results obtained, only microwave power at 1,000 W has a value for ΔE^*_{ab} less than 2 compared to the others. When the ΔE^*_{ab} is more than 2, the colour changes are detectable by reviewer and consumer (Śledź et al., 2013). From the study, there are some changes in the colour as darkening happened, but the colour is close to the original fresh *M. oleifera* leaves as there is only a slight decrease in the value of colour parameter by using microwave drying techniques. This indicates that microwave drying can retain a good and pleasant green colour as the original leaves.

3.3 Protein and iron content

The amount of protein (Figure 2a) in the fresh *M. oleifera* leaves was 7.55 %. Almost similar protein content for fresh *M. oleifera* leaves was reported by Trigo et al. (2021) at 6.7 %. After the drying process, the amount of protein increased to 28.75, 28.50, 28.60 and 28.15 % at 1,000, 800, 500 and 300 W with the loss of moisture. There was no significant difference between the protein content of dried *M. oleifera* leaves at different microwave power levels (P>0.05). This indicates that drying at different microwave power levels (300 W to 1,000 W), exhibited almost the same amount of protein content but at different drying time. The drying time at 1,000 W was shortened by 70 % as compared to drying at 300 W. A shorter drying time is preferable since a prolonged drying time and very high temperature will affect the protein contents in food products due to denaturation of protein cells. The amount of protein in this study was in good agreement with the results by Ali et al. (2017) where the highest amount of protein obtained was 29.8 % at 40 °C of oven drying. The amount of protein obtained in Yashaswini et al. (2021) was slightly higher compared to the current study which was 31.23 % at 450 W. The different amount of protein may be due to the different location and time of harvest (Anjorin et al., 2010). This high amount of protein content indicated the potential of microwave drying method in medicinal and food application due to good preservation amounts of nutrients.

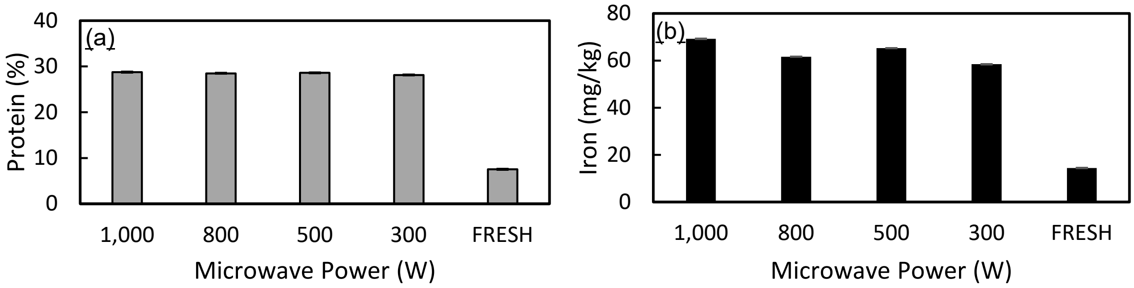


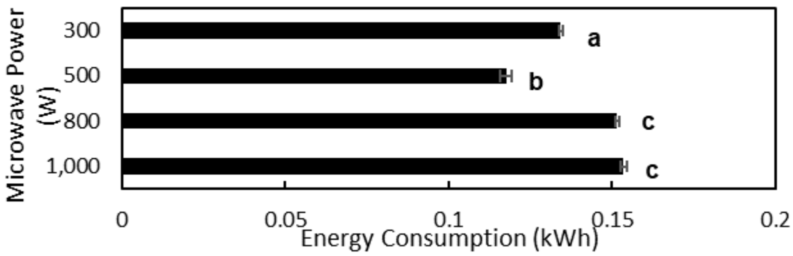
Figure 2: (a) Protein content (b) Iron content for microwave drying of M. oleifera leaves at different power levels

The initial iron content in the fresh *M. oleifera* leaves was 14.46 mg/kg (Figure 2b) and after the drying of *M. oleifera* the amount of iron increased to 58.44, 65.28, 61.66 and 69.23 % at 300, 500, 800 and 1,000 W due to

moisture change. Study by Ali et al. (2017) obtained higher amount of iron in the fresh leaves at 18.7 mg/kg. A significant difference ($P < 0.05$) was observed between the iron content of fresh and microwave dried leaf materials for all microwave power levels. Ali et al. (2017) has reported a higher iron content of 127.2 mg/kg in dried *M. oleifera* leaves using microwave drying at 660 W. The differences might be due to locality of the plantation of *M. oleifera* (Anjorin et al., 2010).
The increase of protein and iron content after drying was due to the difference in nutrient's concentration of internal composition inside the *M. oleifera* leaves as the moisture was reduced (Pati et al., 2011). This indicates that *M. oleifera* leaves have a high amount of iron and protein content when using the microwave drying as it can increase the nutrition amount as well as can preserve its desirable qualities (Yashaswini et al., 2021).

3.4 Energy consumption

Figure 3 shows the energy consumption measured during the microwave drying that was recorded at four different microwave power levels. The unit kWh is a composite energy unit equal to one kilowatt (kW) of power sustained in one hour which is the product of power and time. In this study, the highest energy consumption was recorded at 1,000 W (0.154 kWh) and lowest at 500 W (0.117 kWh). The energy consumptions at microwave power levels (800 and 1,000 W) were found quite similar (0.1525 kWh) with no significant difference ($P > 0.05$). The energy consumption recorded was the lowest at 500 W instead of 300 W due to a shorter period of drying time in 500 W (10 min) compared to 300 W (20 min). When 300 W power was used, the drying time was about 20 min but the absorbed power of the microwave oven was minimal. A longer time was needed at 300 W to reach the same moisture removal as 500 W. A similar behaviour was also reported in previous study by Alibas (2006). This shows that energy consumption is correlated with the absorption of microwave power and drying time.



**A different superscript letter is significantly different (P<0.05)*

Figure 3: Energy consumption for microwave drying of M. oleifera leaves at different power levels

4. Conclusions

Microwave drying of *M. oleifera* leaves shows a great success in reducing the drying time where at 1,000, 800, 500 and 300 W microwave power the drying time were 6, 8, 10 and 20 min. This shows that microwave drying method is a promising alternative for drying of *M. oleifera* leaves at a shorter drying time. The colour, iron, and protein values of the dried leaves were not significantly different compared to fresh leaves. The lowest energy consumption was obtained at power 500 W with 0.117 kWh. The results display a great alternative for the usage of microwave oven as a rapid drying method for *M. oleifera* leaves with a good preservation of its nutrition and qualities and great energy consumption.

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