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Microwave Drying of *Moringa oleifera* (Lam.) Leaves: Drying Characteristics and Quality Aspects

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Abstract

Moringa oleifera (L.) leaves contain significant amounts of bioactive compounds with high antioxidant activities. The aim of this study was to determine drying characteristics using microwave drying (MWD) at different MW powers from 150 to 900 W. Quality aspects in terms of total phenolic content (TPC), DPPH radical scavenging activity, color, rehydration ratio as well as HPLC measurement of quercetin and kaempferol. The drying data were fitted to four drying models. It was found that three parameter model gave the best fit. The drying constant was related to the MW power using an Arrhenius model. Effective moisture diffusivity (D_{eff}) increased with MW power. The dominant antioxidants were measured in terms of TPC, DPPH radical scavenging activity, content of quercetin and kaempferol. All antioxidants were increased with increasing MW powers for both whole-leaf and half-leaf. The dried whole-leaf at 900W yielded the highest TPC, DPPH radical scavenging activity, content of quercetin and the lowest total color difference (ΔE^*). The dried whole-leaf using MWD at 900W were compared with the conventional drying (tray drying at 60°C, 70 min), sun drying (SD) and infrared drying (IRD) in terms of TPC, DPPH radical scavenging activity, contents of quercetin and kaempferol. It was found that the dried whole-leaf using MWD at 900W had the highest TPC, DPPH radical scavenging activity and quercetin content and could increase the retention of TPC (43.28%), DPPH radical scavenging activity (25.64%) and quercetin (64.10%). Therefore, the commercial processing of *M. oleifera* leaves could be improved by using MWD, as the drying time was considerably reduced and the dried *M. oleifera* leaves had a higher TPC, DPPH radical scavenging activity and quercetin.

Keywords: *Moringa oleifera, Microwave drying, TPC, DPPH radical scavenging activity, Quercetin*

1. Introduction

Moringa oleifera Lam. (Family: *Moringaceae*) is commonly known as the horseradish or drumstick tree. It is called "Ma-rum" in Thailand. *M. oleifera* is valued mainly for tender pod, flower and leaves, which are esteemed as a vegetable. Immature pods and leaves are the most widely used. In addition, *M. oleifera* are used in traditional medicine for the treatment of human diseases, including the treatment of infectious diseases along with cardiovascular, gastrointestinal, hematological, hepatorenal disorders, antibacterial, antitumor, diabetes and skin disorders (1-3). The leaves are rich source of vitamin A and C, essential amino acids, such as methionine, tryptophan and lysine with a high content of protein (4). Moreover, *M. oleifera* leaves contain various phytochemical and function as antioxidants (5). Nair and Subramanian, 1962 (6) reported that *M. oleifera* leaves contain flavonoids, including kaemferol, rhamnetin, isoquercetrin, and kaempferitrin. The major bioactive compounds of flavonoids group, such as quercetin and kaempferol (7). The shelf-life of fresh *M. oleifera* leaves is only 2 to 3 days. Drying is helping reduce the water activity and could reduce the postharvest loss. Drying offers a means of preserving foods in a stable and safe condition because it reduces water activity and extends the shelf-life much longer than fresh leaves (8).

In general, the commonly used drying methods are sun drying and tray drying. However, their disadvantages include contamination problem, long drying times, inability to handle the large quantities and achieving consistent quality standard. Microwave drying (MWD) is an alternative method because of its uniform energy and high thermal conductivity to the inner sides of the material, precise process control, fast start-up and shutdown conditions, energy savings and MWD offers opportunities to shorten the drying time and improves the final quality of the dried products (9,10).

Many mathematical models have been developed to calculate the time of drying under the given operating conditions. Modeling and optimization to increase the efficiency of drying is the most important stage in process design (11). The study of the drying kinetic of foods using MWD has recently been a subject of interest for various investigators. Some of the previous studies about MWD drying can be listed as; carrot (12-15), parsley (16), chard leaves (17), black tea (18), spinach (19), mint (20) and *M. oleifera* pods (8).

In review of no data on drying kinetics of *M. oleifera* leaves, the MWD is a popular alternative drying method for a wide variety of fruits and vegetables. However, the MWD research so far focused mainly on the fundamental aspects rather than industrial application.

Therefore, the aim of this study was to determine drying characteristics using MWD at different output powers from 150 to 900 W that resulted in the optimum drying kinetic model of dried whole-leaf and half-leaf of *M. oleifera* leaves. Quality aspects of the dried leaves were determined in terms of total phenolic content (TPC), DPPH radical scavenging activity, color, rehydration ratio as well as HPLC measurement of quercetin and kaempferol. The best quality in this work was compared with a conventional dried powder samples (tray dryer) and commercial practices in order to obtain the highest TPC, DPPH radical scavenging activity and content of quercetin and kaempferol.

2. Materials and methods

2.1 *M. oleifera* leaves

Appropriated maturity stage of fresh *M. oleifera* leaves which was the primary to the tertiary compound leaf from the top of branches of a tree (21) was used in the drying experiments. It was harvested from the research field of the Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand. The *M. oleifera* trees were grown under identical conditions in terms of fertilization, irrigation, and herbicide treatments. The leaves were removed from each branch, then cleaned using tap water and left for 30 mins in the ambient air to allow the surface water to dry and half cut perpendicular to the axis of the leaves. The leaves were divided into two groups: whole-leaf (W) and half-leaf (H).

2.2 Drying equipment and drying method

Microwave drying

Drying was accomplished in a microwave system (Electrolux 30 liter, EMS3067x, AB Electrolux, Stockholm, Sweden) with a magnetron operating at a frequency of 2,450 MHz (λ=12.14 cm). The microwave system was set to deliver power at 150W (30% setting), 450W (50% setting) and 900W (100% setting). *M. oleifera* leaves of 12 g were placed on the 35 cm diameter glass turntable and caused to rotate in both clockwise and counterclockwise directions at regular time intervals at 4 rpm/min. The direction of the rotations was able to be changed with the exterior on/off switch.

During MWD drying, moisture content was monitored by periodically removing the turntable (with sample) and weighing it on a digital balance to the nearest 0.01 g. The weighing process was completed within 10 s. Drying was terminated when the moisture content of the samples was reduced such that the a_w was less than 0.6. The experiments were replicated three times for each drying condition.

Mathematical modeling of drying data

The changing product weight was used to calculate moisture content and moisture ratio (X/X_o) as a function of time. The moisture ratio data were fitted by four different thin-layer models as shown in Eq. 1 to 4

Henderson and Pabis (22); $X/X_0 = A\ exp(-Kt)$ (1)

Modified Page (23); $X/X_0 = exp\ (-Kt)^N$ (2)

Zero model (24); $X/X_0 = exp(-Kt)$ (3)

Three parameter model (25); $X/X_0 = A\ exp\ ((-Kt)^N)$ (4)

These included the Henderson and Pabis, Modified Page, Zero, and three parameter models. Regression analysis was used to determine the constants *K*, *A* and *N*. The effective moisture diffusivity (D_{eff}) was calculated using the simplified solution of Fick's second law (Eq. 5). The effective moisture diffusivity, D_{eff}, was obtained by fitting the drying data to a diffusion model (26):

$$\frac{X}{X_0} = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right] \quad (5)$$

For MWD, it is difficult to measure temperature directly in the system. Thus, a modified version of the Arrhenius equation may be used to illustrate how the rate constant (or diffusivity) varies with the sample amount (*m*) and microwave output power (P). Also, the activation energy (E_a) was determined using Eq. 6 and 7 (27):

$$K = K_0 \exp\left(-E_a \cdot m / P\right) \quad (6)$$

$$D_{eff} = D_0 \exp\left(-E_a \cdot m / P\right) \quad (7)$$

The best model describing the thin-layer drying for whole-leaf (W) and half-leaf (H) of *M. oleifera* was chosen as the one with the highest coefficient of determination (R^2), lowest standard error of estimate (SEE), and lowest root mean square error (RMSE).

$$SEE = \sqrt{\frac{\left(\sum_{i=1}^{n} (X_{pre,i} - \overline{X}_{exp,i})^2\right)}{d.f}} \quad (8)$$

$$RMSE = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n} (X_{pre,i} - \overline{X}_{exp,i})^2\right)} \quad (9)$$

where *n*-1 describes the degrees of freedom of the fitting equation.

2.3 Qualities aspects evaluation

Total phenolic content (TPC), DPPH radical scavenging activity, content of quercetin and kaempferol

Sample extraction

Extraction was carried out following the modified methods of Siddhuraju and Becker (7), Lako and others (28) and Sultana and Anwar (29). Sixty percent aqueous methanol (40 mL) containing 2 g/L of terbutylhydroxyquinone (TBHQ) was added to each 0.5 g of dried *M. oleifera* leaves. Ten milliliters of 6M HCl were added and the solution was refluxed at 90°C for 2 hours to obtain aglycons of flavonol glycosides. The extract was cooled to room temperature. Upper layer was taken and the extract was filtered through a Whatman paper No.1. The final extracted were used to determine total phenolics, total flavonoids and DPPH radical scavenging activity. For analyzing of quercetin and kaemferol by HPLC, the final extracts were filtered through a 0.45m*m* (Millipore) filter.

Total phenolic content (TPC)

The concentration of TPC in extracts was measured by UV-visible spectrophotometer (LAMDA 25, PerkinElmer, America), based on a colorimetric oxidation/reduction. The oxidizing agent used was Folin-Ciocalteu reagent (FCR). Samples (0.5 mL) or gallic acid standard solution were mixed with 2.5 mL of Folin-Ciocalteu's reagent (FCR-1:10 dilution) and left to stand for 8 min at room temperature to allow for the FCR to react completely with the oxidizable substances or phenolates. Two milliliters of sodium carbonate, Na_2CO_3 (7.5% w/v solution in water) was added to destroy the residual reagent. The absorbance was measured at 760 nm after standing at room temperature for 2 hours. Quantitative measurements were performed, based on a standard calibration curve of gallic acid in methanol. The mean (±SD) results of triplicate analyses were expressed as gallic acid equivalent (GAE) in mg/g dry weight (28).

DPPH radical scavenging activity

Seventy seven mL of extracts were added to 3 ml of 2, 2-diphenyl-1-picylhydrazyl (2.4 mg/100 mL methanol). Deionized distilled water was used as control. The mixture was vortex-mixed and allowed to stand for 15 min in a dark cabinet at room temperature before absorbance at 515 nm was measured. Methanol was used to calibrate the spectrophotometer (LAMDA 25, PerkinElmer, America). To test the stability of DPPH, methanol was used as a blank. Radical-scavenging ability was calculated as percentage inhibition of DPPH radical (29).

$$\text{DPPH scavenging activity} = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}} \times 100 \quad (10)$$

Content of quercetin and kaempferol by HPLC Analysis

The flavonols quercetin and kaempferol were determined using high performance liquid chromatography (Water 600 Quat pump, Water 600E Controller, Water 717 plus Auto sampler and Millenium Software, Sciencetific Incorporation, Canada). Ten microliters of the filtered sample were injected to a reverse-phase HI5C18 column (150 mm x 4.6 mm, 5 mm) (HiChrom Co. Ltd, Reading, UK), which was maintained at an oven setting of 40°C. Two solvent systems were prepared for elution, containing (A) 0.5% trifluoroacetic acid and (B) 100% acetonitrile. Separations were attained using gradient elution of the mobile phase (mixtures of solvents A and B) as follows: 90% A: 10% B from 0 to 14 min; linear gradient of 55% A: 45% B; linear gradient of 0% A:100% B for 15-18 min; isocratic conditions of 90% A:10% B for 19-30 min. A flow rate of 1 ml/min was used and absorbance at 370 nm was monitored at the detector (7, 28, 30).

Identification of quercetin and kaempferol was done by comparing their retention times with those of authentic standards (Sigma-Aldrich (M) Sdn. Bhd, Selangor, Malaysia). The compounds were quantified based on calibration curves developed from the standards using peak areas. All runs were carried out in triplicate and the mean results were expressed as mg/100g dry weight.

Color Measurements

The color of the *M. oleifera* leaves was measured before and after drying using a HunterLab UltraScan XE U3115 colorimeter (Hunter Associates Laboratory, Reston, Virginia). Color values were measured using the CIE L^*, a^*, b^* color space. The scale represents the range of L^* from 0 to 100 (black to white), $-a^*$ (green) to $+a^*$ (red), and $-b^*$ (blue) to $+b^*$ (yellow). Measurements were taken using CIE Illuminant C and the instrument was calibrated using a standard white tile reflector. a^*/b^*, chroma ($[a^{*2}+b^{*2}]^{1/2}$), total difference change color (ΔE^*), Hue and browning index (*BI*) were also determined to evaluate green-yellow color of the leaves.

$$\Delta E^* = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2} \quad (11)$$

where L_0, a_0, b_0 are the color values of fresh *M. oleifera* leaves; L^*, a^*, b^* are the color values after drying.

The browning index (*BI*) has been developed to measure the degree of browning in dried products (31). *BI* represents the purity of brown color and is given by

$$\text{BI} = \left[\frac{100\left(\text{x} - 0.31\right)}{0.17}\right] \quad (12)$$

where,

$$\text{x} = \frac{\left(\text{a}^* + 1.75L^*\right)}{\left(5.645\text{L}^* + \text{a}^* - 3.012\text{b}^*\right)} \quad (13)$$

Rehydration ratio

Rehydration properties were measured by immersing dried *M. oleifera* leaves in distilled water maintained at ~30°C. Approximately 3 g of the dried leaves were added to 150 mL of distilled water (1:50 w/w). Samples were removed from the water, drained over a mesh filter for 60s to remove superficial water, and

then blotted with tissue paper. The weight was measured with a digital balance. The rehydration ratio was calculated as the weight of the drained sample compared to the weight of dried sample (32).

2.4 Statistical analysis

A completely randomized 2x3 factorial experiment was used to study the main factors of the leaf group (whole-leaf and half-leaf) and the MW power at 150, 450 and 900W. The best treatment from this study was compared with the dried samples from the tray drying at 60°C for 70 mins (Model UOP8, Armfield Limited, Ringwood Hampshire, England) (21) and the two types of dried samples in commercial practice (sun drying sample, SD and infrared drying sample, IRD). The dried *M. oleifera* leaf powder were purchased in the supermarket in Khon Kaen, Thailand. Complied data were present as mean and standard deviation of the mean (mean±standard deviation). The analysis of variance was performed by ANOVA procedures. Significant differences of the means were determined by Duncan's multiple range tests. Significances of differences were defined at $p \leq 0.05$. The experimental analysis and data fitting were processed using the softwere of package program, SPSS version 19.0 for Windows (SPSS, Inc., Chicago, IL).

3. Results and discussion

3.1 Drying Kinetic models

The mathematical drying models for thin-layer drying were fitted by moisture ratio (MR) and drying time. In MWD field, the temperature rise of the drying material is driven internally at a rate governed by the intensity of the electromagnetic stimulation of water molecules. The temperature and relative humidity of the external air stream are no longer the factors affecting the equilibrium moisture content. Therefore, in this study, the MR could be simplified to X/X_0. The initial moisture content (X_0) at the beginning of each drying experiment was 72.47% w.b. (264.11% d.b.). The drying was terminated when final the moisture content of the samples was reduced to 5.14% w.b. (5.54% d.b.) which corresponded with the a_w of 0.6 for a safe level.

Experimental conditions for the microwave drying (MWD) are shown in Tables 1 and 2. Table 1 shows the goodness of fitting results for each of the four models shown including the Henderson and Pabis (HP), Modified Page (MP), three parameter (TP) and Zero (ZR) models. The results from Table 1 and Figure 1 revealed that TP model was the best model to describe the mass transport of moisture in the drying of *M. oleifera* leaves. The highest R^2 and lowest SEE and RMSE were attained with the TP model for both whole and half-leaf at three microwave output powers. Table 2 shows the predicted constants from the TP model with respect to the constants *K* and *N*. The constant *A* was an exponential term in order to describe experimental data affected by diffusion of moisture. The drying rate constant *K* was greater when the samples were half cut. Thus, the half-leaf helped increase the rate of drying. The tissues of whole-leaf were damaged by cutting which might enhance release of cell compositions. In addition, the whole-leaf and half-leaf showed a different size and leaf diameter. Bahloul, 2008 (33) explained in terms of difference in surface porosity which consequently affect the phenomenon of capillary condensation. The drying rate constant was fitted to the analogous Arrhenius equation for power (Eq. 6), and the constants are shown in Table 2. As expected, the *K* values increased with the microwave power output. The higher microwave power resulted in greater rates of moisture removal, and an enhancement

of drying potential (34-35). The drying curves for MWD *M. oleifera* leaves are shown in Figure 1. All of the MWD drying occurred in falling rate drying (Figure 1). As noted, a constant rate period was not observed. Similar findings have been reported for various food materials (27, 34-36)

Table 1. Results of statistical analysis on the modeling of *M. oleifera* leaves

Treatment	MW	R^2				SEE				RMSE			
	power	HP	MP	TP	ZR	HP	MP	TP	ZR	HP	MP	TP	ZR
Whole-leaf (W)	150W	0.973	1.000	**1.000**	0.958	0.0576	0.0065	**0.0065**	0.0717	0.0556	0.0063	**0.0063**	0.0693
	450W	0.974	0.996	**0.996**	0.966	0.0602	0.0226	**0.0224**	0.0689	0.0571	0.0214	**0.0212**	0.0653
	900W	0.982	0.996	**0.996**	0.981	0.0600	0.0274	**0.0274**	0.0608	0.0537	0.0245	**0.0245**	0.0544
Half-leaf (H)	150W	0.976	0.989	**0.992**	0.975	0.0505	0.0342	**0.0298**	0.0523	0.0488	0.0331	**0.0288**	0.0505
	450W	0.989	0.998	**0.998**	0.987	0.0396	0.0181	**0.0177**	0.0421	0.0371	0.0170	**0.0166**	0.0394
	900W	0.979	0.997	**0.997**	0.978	0.0705	0.0277	**0.0277**	0.0716	0.0610	0.0240	**0.0240**	0.0620

Table 2. Drying time, K, N and A values obtained from the Three parameter model, D_{eff}, and activation energy (E_a) predicted from drying constant, K and D_{eff} using the fitted Arrhenius model [Eqs. (6)-(7)] for microwave drying

Leaf	MW	Drying time	K	N	A	D_{eff}	R^2	K_0	E_a	R^2	SEE	RMSE	D_0	E_a	R^2	SEE	RMSE
	power	(min)	(min^{-1})			(m^2/s)		(1/min)	W/g		(1/min)	(1/min)	(m^2/s)	W/g		(m^2/s)	(m^2/s)
Whole-leaf	150W	15	0.1551	1.5021	1.0005	3.17199E-11	0.858	1.5539	55.8413	0.899	0.0990	0.0808	4.26707E-10	67.63	0.921	0.0000	0.0000
(W)	450W	10	0.3026	1.4641	1.0126	6.32654E-11	0.886										
	900W	5	0.7522	1.6450	1.0010	1.74725E-10	0.923										
Half-leaf	150W	15	0.1648	1.4010	0.9414	3.64166E-11	0.907	1.0153	29.0571	0.949	0.0682	0.0557	2.3199E-10	31.07	0.939	0.0000	0.0000
(H)	450W	8	0.4047	1.2706	0.9937	8.6583E-11	0.925										
	900W	4	0.7646	1.6193	1.0014	1.70906E-10	0.922										

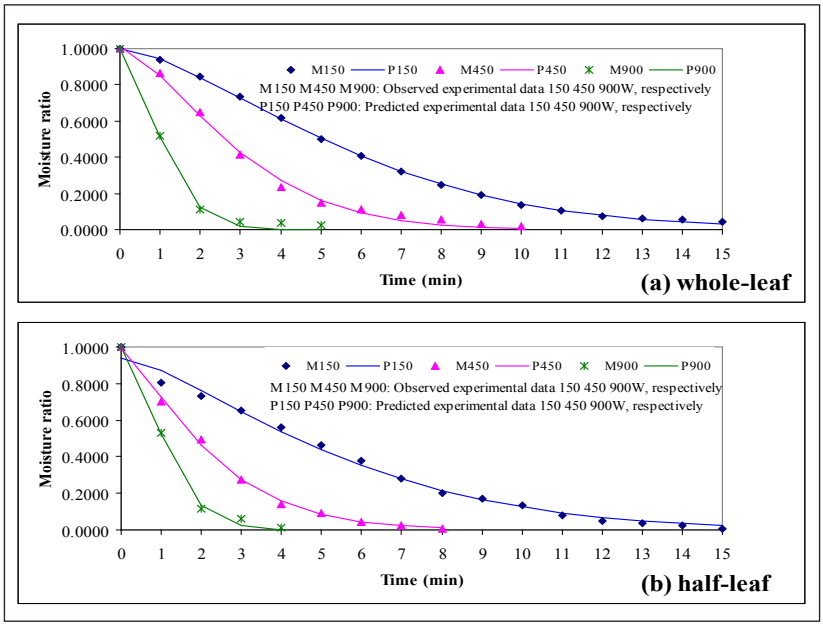

Figure 1. Experimental and predicted data for moisture ratio from the three parameter model of *M. oleifera* leaves; (a) whole-leaf, (b)half-leaf using MWD at 150, 450 and 900W

Effective Moisture Diffusivities

The effective moisture diffusivity (D_{eff}) at different microwave powers (150-900 W) for MWD are shown in Table 2. D_{eff} values for MWD were ranged from $3.17x10^{-11}$ to $1.75x10^{-10}$ m^2/s and $3.64x10^{-11}$ to $1.71x10^{-10}$ m^2/s for whole-leaf and half-leaf, respectively and increased with microwave power. Minimal processing such as cutting caused microstructure changes to the exterior surface of *M. oleifera* leaves, leading to increase rates of water loss and the increase of the D_{eff}. While no values of D_{eff} were found in the literature for *M. oleifera*, the values measured here were generally similar to other dried food in MWD, such as basil leaves (37), mint leaves (*Mentha spicata* L.) (20), celery leaves (38), and coriander leaves (39). Those samples were dried at 180 to 900 W, and resulted in D_{eff} values in the range of 10^{-10} to 10^{-11} m^2/s.

Activation Energy

The activation energies (E_a) for the dried *M. oleifera* leaves were determined for MWD (Table 2). A modified form of the Arrhenius model was used for MWD using *m*/P instead of temperature as the relevant independent variable. The literatures for different agricultural products were providing E_a of 5.54 W/g mentioned for okra (27) and 12.28 W/g for mint leaves (20). The values of E_a indicated in term the K-m/P and the D_{eff}-m/P, which were reported the values of 0.9530 and 1.048 W/g for white part of leek, and 1.205 and 1.131 W/g for green parts of leek (10), respectively which were lower than E_a of this work.

3.2 Total phenolic content (TPC), DPPH radical scavenging activity, content of quercetin and kaempferol

Total phenolic content (TPC) were determined from the calibration curves of gallic acid (Y_{Abs} = 0.1081x+0.0721, R^2=0.9990). Antioxidant activity was reported in term of DPPH radical scavenging activity. Quercetin and kaempferol were flavonoids in *M. oleifera* leaves. It was found that all the dried samples showed a significant increase in TPC, DPPH radical scavenging activity, quercetin and kaempferol ($p \leq 0.05$) with increasing MW output power from 150-900W for both whole-leaf and half-leaf (Table 3).

Table 3. Total phenolic content (TPC), DPPH radical scavenging activity, content of quercetin and kaempferol of *M. oleifera* leaves after drying using microwave dryer

Leaf[1]	MW power (Watt, W)	TPC (mg/g d.b.)	DPPH radical scavenging activity (%)	Quercetin (mg/100g d.b.)	Keampferol (mg/100g d.b.)
Whole-leaf (W)	150	10.95^{c}±0.41	40.85^{c}±0.63	30.85^{c}±1.52	**8.42^{a}±1.56**
	450	12.42^{b}±0.33	43.24^{b}±0.37	38.17^{b}±0.47	**7.03^{a}±2.71**
	900	**14.28^{a}±0.89**	**46.33^{a}±0.03**	**57.46^{a}±1.29**	**7.82^{a}±0.62**
Half-leaf (H)	150	8.76^{e}±055	28.91^{f}±0.89	11.56^{f}±1.04	5.04^{b}±1.07
	450	9.74^{d}±0.18	33.18^{e}±0.64	18.68^{e}±0.99	4.31^{b}±0.38
	900	10.11^{cd}±0.32	36.62^{d}±0.98	26.75^{d}±0.60	6.18^{b}±1.00

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

[1] Fresh leaves: TPC (12.69 mg/g d.b.), DPPH radical scavenging activity (37.94%), Quercetin (2.88 mg/100g d.b.), Keampferol (1.22 mg/100g d.b.)

The levels of TPC, DPPH radical scavenging activity and quercetin in the whole-leaf were greater than half-leaf. During thermal processing, the increase in the total phenolics, antioxidant activity and flavonoids because bound phytochemicals were released from the matrix. A possible synergistic effect with other phytochemicals, such as phenolics and flavnonoids might be involved (40). In addition, the minimal processing, such as cutting might damage the cell wall fraction and enhance the release of phytochemicals from the matrix resulting in an easier release of bond polyphenolics and flavonoid compounds in half-cut leaves (41).

The dried whole-leaf samples at 900W provided the highest retention of TPC (29.20%), DPPH radical scavenging activity (20.96%) and quercetin (53.45%) and higher than the dried half-leaf samples.

Color Values

The greatest greenness index (a^*/b^*) and chroma value (C^*) were attained for dried whole-leaf samples (Table 4). In addition, dried whole-leaf samples at 900W provided the lowest changes of ΔE^*.

Table 4. Color values and rehydration ratio of *M. oleifera* leaves after drying using microwave dryer

Leaf	MW power (Watt, W)	Color values[2] L*	a*	b*	a*/b*	C*	ΔE*	Hue*	Browning index (BI)	Rehydration ratio
Whole-leaf (W)	150	45.49^{a}±2.92	-5.55b^{c}±0.89	10.88^{abc}±2.14	-0.52^{b}±0.02	12.22^{ab}±2.31	16.29^{a}±0.17	152.05^{b}±1.04	16.97^{a}±3.14	3.83^{a}±0.01
	450	45.70^{a}±2.76	-6.60a^{b}±096	11.46^{ab}±1.98	-0.58^{a}±0.04	13.23^{a}±2.15	15.68^{b}±0.34	149.93^{c}±1.95	16.61^{a}±3.00	3.88^{a}±0.19
	900	45.24^{a}±1.08	-6.97^{a}±041	11.98^{ab}±0.95	-0.58^{a}±002	13.85^{a}±1.03	14.71^{c}±0.14	149.79^{c}±0.60	17.65^{a}±2.34	3.91^{a}±0.07
Half-leaf (H)	150	42.75^{b}±1.56	-3.86^{d}±047	8.52^{c}±0.83	-0.45^{c}±0.04	9.36^{c}±0.91	16.87^{a}±1.18	155.64^{a}±1.63	14.73^{a}±1.65	3.70^{a}±0.05
	450	42.75^{b}±1.56	-4.67^{cd}±0.30	9.00^{bc}±0.99	-0.52^{b}±0.03	10.15^{c}±1.01b	16.18^{b}±0.06	153.21^{b}±0.43	14.53^{a}±1.74	3.78^{a}±0.21
	900	44.19^{b}±0.38	-6.61^{ab}±0.06	11.00^{abc}±0.02	-0.60^{a}±0.01	12.83^{ab}±0.04	14.73^{c}±0.23	148.82^{c}±0.20	16.02^{a}±0.18	4.44^{a}±0.01

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

[2] Fresh leaves: L*=39.91, a*=-11.29, b*=21.43, a*/b*=-0.53, C*=24.22, hue*=152.07

Rehydration Ratio

Table 4 shows the results for rehydration ratio for the different dried samples. However, the rehydration ratio of rehydrated leaves were not significantly different. In general, the best rehydration was obtained in samples that had short drying times.

The selected dried whole-leaf using MWD at 900W was the best drying conditions of *M. oleifera* leaves. The dried whole-leaf using MWD at 900W were compared with the conventional drying (tray drying at 60°C for 70 mins drying time) (21), SD and IRD in terms of TPC, DPPH radical scavenging activity, quercetin

and kaempferol. It was found that the dried whole-leaf at 900W, SD and IRD provided the higher kaempferol content ($p \leq 0.05$) than the conventional drying tray drying. In addition, the dried whole-leaf using MWD at 900W had the highest TPC, DPPH radical scavenging activity and quercetin ($p \leq 0.05$) (Table 5, Figure 2) and could increase the retention of TPC (43.28%), DPPH radical scavenging activity (25.64%) and quercetin content (64.10%). Therefore, dried *M. oleifera* leaves using MWD at 900W was the most suitable drying condition. It is the useful information for practical or commercial of *M. oleifera* leaves drying. Moreover, it might be considered a useful tool for improving phytochemical compounds of dried *M. oleifera* leaves.

Table 5. Comparison of total phenolic content (TPC), DPPH radical scavenging activity, content of quercetin and kaempferol of *M. oleifera* leaves obtained from using tray drying at 60°C, whole-leaf using microwave at 900W, SD and IRD

Treatment	TPC (mg/g d.b.)	DPPH radical scavenging Activity (%)	Quercetin (mg/100g d.b.)	Kaempferol (mg/100g d.b.)
Tray drying at 60°C	$9.10^{bc} \pm 0.54$	$40.82^{b} \pm 0.29$	$32.36^{b} \pm 0.88$	$4.16^{b} \pm 0.17$
Whole-leaf at 900W	$14.28^{a} \pm 0.89$	$46.33^{a} \pm 0.03$	$57.46^{a} \pm 1.29$	$7.82^{ab} \pm 0.62$
SD[3]	$8.10^{c} \pm 0.61$	$34.45^{d} \pm 0.88$	$20.63^{d} \pm 0.15$	$8.31^{ab} \pm 2.59$
IRD[4]	$10.09^{b} \pm 0.72$	$38.66^{c} \pm 0.59$	$26.28^{c} \pm 1.32$	$10.36^{a} \pm 4.10$

Different superscripts in the same column mean that the values are significantly different ($p \leq 0.05$).

[3] Sun drying sample in commercial practice in Khon Kaen province

[4] Infrared drying sample in commercial practice in Nakhon Pathom province

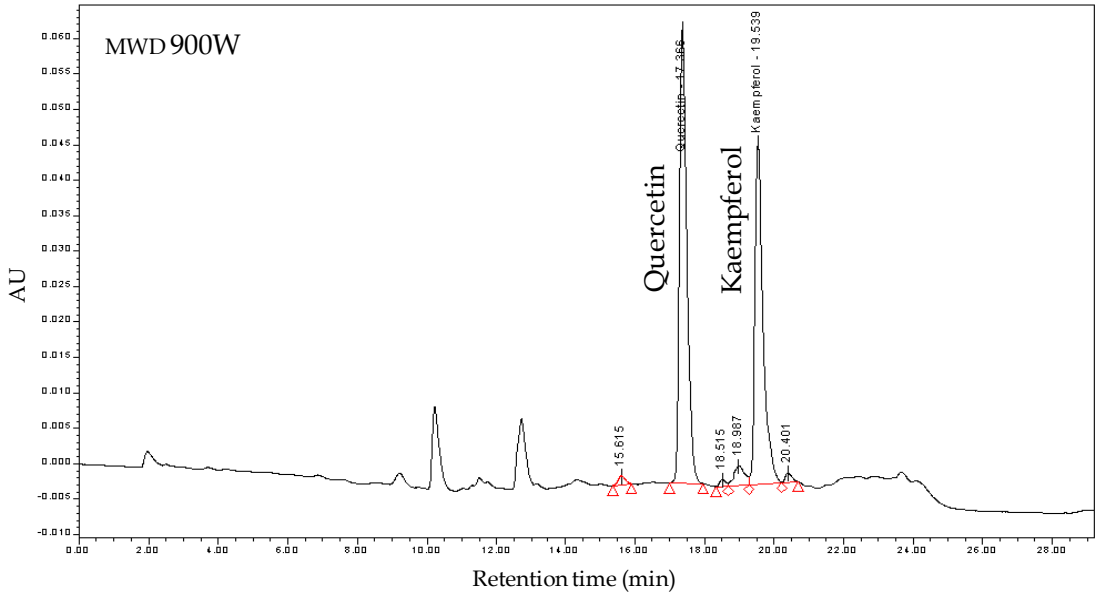

Figure 2. Chromatograms of dried *M. oleifera* leaves by MWD at 900 W

4. Conclusion

Moringa oleifera (L.) leaves contain significant amounts of bioactive compounds with high antioxidant activities. The MWD samples were the best fitted to the three parameter model, which gave three empirical drying constants (*K, A* and *N*). The constant K in the model was related to the MW output power. The effective moisture diffusivities could be calculated in a range from $3.17x10^{-11}$ to $1.75x10^{-10}$ m^2/s and $3.64x10^{-11}$ to $1.71x10^{-10}$ m^2/s for whole-leaf and half-leaf, respectively and were increased with microwave output power. The activation energy values were obtained from Arrhenius model. Microwave drying application significantly increased the phytochemical compounds of *M. oleifera* leaves. TPC, DPPH radical scavenging activity, quercetin and kaempferol of *M. oleifera* leaves were easier to extent when a higher MW output power was reached. Dried whole-leaf using MWD at 900W had the highest TPC, DPPH radical scavenging activity and quercetin when compared with conventional drying, such as TD at 60°C for 70 mins drying time and 2 type of dried powder samples in commercial practices (SD and IRD). This information could be beneficial for commercial drying of *M. oleifera* leaves using MWD, which considerably reduced the drying time and remained the high retention of TPC, DPPH radical scavenging activity and quercetin content.

Nomenclature

D_{eff}	Effective moisture diffusivity (m^2/s)
D_0	Pre-exponential factor (m^2/s)
E_a	Activation energy (J/mol×K or W/g)
K	Drying constant (min^{-1})
K_0	Pre-exponential factor (min^{-1})
L	Half thickness of *M. oleifera* leaf (m)
MR	Moisture ratio (X_t/X_0)
N	Drying exponent
P	Microwave power (Watt, W)
R^2	Coefficient of determination
RH	Relative humidity (decimal)
RMSE	Root mean square error
SEE	Standard error of estimate
T	Temperature (°C)
t	Time (min)
X	Moisture content (% d.b.)
X_0	Initial moisture content (% d.b.)
$X_{exp,i}$	Experimental moisture content, the i^{th}
$X_{pre,i}$	Predicted moisture content, the i^{th}
X_t	Moisture content at time (% d.b)

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