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Microwave drying characteristics and qualities of dried *Orthosiphon aristatus* leaves

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Abstract

Orthosiphon aristatus (OA) is widely used in the Southeast Asia as a traditional remedy for various ailments and diseases, such as kidney stones, high blood pressure, diabetes, rheumatism, arthritis, gout and possibly other ailments. Vacuum blanched and unblanched OA leaves were dried in a microwave dryer (MWD) at 450, 720 and 900 W. The drying data were fitted to four thin layer drying models to describe microwave drying characteristics of the OA leaves. Physical and chemical properties were evaluated. The results revealed that Three parameter model was the suitable drying model to describe drying data as a result of the highest coefficient of determination (R^2) and the lowest standard error of estimate (SEE) and root mean square error (RMSE). The drying times could be reduced by 66.7% and 50.0% for unblanched and vacuum blanched treatments, respectively with increasing microwave outputs from 450 W to 900 W. Dried OA leaves using MWD at 720 and 900 W in both treatments (vacuum blanched and unblanched) provided the lowest total color difference. Vacuum blanched and dried OA leaves using MWD at 900 W had more porous and less cell damage than other treatments. For chemical properties, vacuum blanched and dried OA leaves using MWD at 900 W also provided the highest total phenolics, sinensetin and eupatorin contents. Vacuum blanched and dried OA leaves using MWD at 900 W were recommended using in the drying process of OA leaves.

Keywords: Antioxidant, drying model, Java tea, microwave drying, Orthosiphon aristatus, scanning electron microscope

1. Introduction

Herbal products have been traditionally used as therapeutic agents and dietary supplements in both Eastern and Western cultures. Market value for Thai herbal products in 2011 has been estimated to be worth 23.14 billion Baht (0.76 billion USD). Market value of herbal drink is growth of 32%. Thai herb market export value in 2011 and 2012 are 350.90 and 443.12 million Baht (11.51 and 14.26 billion USD), respectively. Thai herb market export value is increased about 26.28% [1].

Orthosiphon aristatus leaves (OA leaves) are also known as Java Tea leaves and the other names for Java Tea are *Orthosiphon stamineus* Benth, *Orthosiphon grandiflorum*, Yaa Nuat Maeo, Cat's Whiskers, Kidney Tea, Misai Kucing and Kapen Prey. OA is a traditional medicinal herb found mostly throughout the South East Asia that is widely grown in tropical areas. It can act as antiallergic, antihypertensive, anti-inflammatory, antiproliferative and diuretic properties. OA leaves are widely used to prevent various ailments and diseases, such as kidney stones, high blood pressure, diabetes, rheumatism, arthritis, gout and possibly other ailments. The specific polyphenol components that are dominant in the leaves of the Java Tea herb consist of four main polymethoxylated flavones, which are sinensetin (SEN), eupatorin (EUP), 3'-hydroxy-5,6,7,4'-tetramethoxyflavone (TMF) and rosmarinic acid (RA), which is the major phenolic acid [2].

Most herbs, fruits and vegetables contain more than 80% water and are therefore highly perishable. Drying is one of the most energy-intensive unit operations that applied to reduce the water content of products. The purpose of reducing the water content is to prolong the shelf-life of the products by reducing the water activity to a low level where growth of microorganisms, enzymatic reactions, and other deteriorative reactions are inhibited. Open-air sun drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other

agricultural or forest products as a means of preservation. However, for large-scale production the limitations of open-air drying are well known. Among these are high labor costs, large area requirement, lacking of ability to control the drying process, possible degradation due to biochemical or microbiological reactions and insect infestation. Hot air drying is a conventional drying method which is used to produce dried products [3] but this drying method has long drying time leading to decrease the qualities of the products including high cell damage and decreasing bioactive compound and also has low energy efficiency. Microwave drying is an alternative drying method to dry an agricultural product. Microwave drying is based on so called dielectric heating, in which energy is absorbed by ions or molecules that are either induced or permanent dipoles. The potential advantages of microwave and dielectric drying compared to conventional drying are more rapid process and more uniform heating which can lead to improved quality and higher yield, higher energy efficiency, better and more rapid process control, less floor space, and more selective heating [4].

Drying models are used in drying process to predict drying characteristics, drying constant and drying time, to control drying process leading to retain high quality of dried products. Thin layer drying models can be divided into 3 groups, namely theoretical, semi-theoretical and empirical models. The models are used as a tool to estimate the drying characteristics of dried products from experimental data. The theoretical model assumed that the rate of moisture loss of a food surrounded by air is proportional to the difference between the food moisture content and its equilibrium moisture content, such as the Henderson and Pabis model (equation (2) in Table 1). For the semi-theoretical model, the equilibrium moisture content of food is close to 0. Therefore, the Newton model was modified to the Modified Zero model (equation (3) in Table 1). Empirical models neglect internal resistance to mass transfer and based on test results, such as the Modified Page and Three parameter models (equation (1) and (4), respectively in Table 1).

Table 1 Mathematical modeling

Model name	Model	Equations
Modified Page (MP)	$\frac{M}{M_o} = exp(-Kt)^N$	(1)
Henderson and Pabis (HP)	$\frac{M}{M_o} = A\,exp(-Kt)$	(2)
Modified Zero (MZ)	$\frac{M}{M_o} = exp(-Kt)$	(3)
Three parameter (TP)	$\frac{M}{M_o} = A\,exp[(Kt)^N]$	(4)
Moisture diffusivity (D_{eff})	$\frac{M}{M_o} = \frac{8}{\pi^2} exp\left[-\frac{\pi^2 D_{eff} t}{4L^2}\right]$	(5)
Activation energy	$K = K_0 \exp(-\frac{E_a m}{P})$	(6)
	$D_{eff} = D_0 \exp(-\frac{E_a m}{P})$	(7)

Most of the previous studies on chemical composition of the OA leaves have focused on quality of bioactive compounds [5, 6, 7]. There is no available report regarding the effectiveness of microwave drying of the OA leaves. Selection of a suitable model plays an important role on the goodness of model fitting in describing the drying of a product. Therefore, knowledge of such physical and chemical characteristics of the products as heat and mass transfer as well as the effective moisture diffusivity is important and indispensable. The aims of this research were to study the effects of vacuum blanching pretreatment and microwave power levels on drying characteristics, physical and chemical qualities of dried products in terms of color values, microstructure changes, total phenolics, %inhibition and bioactive compounds and select the suitable drying conditions for the OA leaves which provided the highest bioactive compounds.

2. Material and Methods

2.1. Material

OA leaves were harvested from a private garden in Kalasin province, Thailand. The fresh samples, flower bud stage; 49-56 days, were cleaned in 5 ppm chlorinated water, and stored at 10°C for not more than 1 day before use. The average initial moisture content of OA leaves was 87.19±0.57% (w.b.) as determined by hot air oven at 105 °C [8]. The OA leaves were vacuum packed in vacuum bags (Polyamides/Polyethylene) before blanching. The vacuum blanching for 75 s was used to inhibit enzymatic browning during drying because it could retain the highest bioactive compounds [9].

2.2. Drying Process

The drying procedure was carried out by a microwave oven (Electrolux, model EMS3067X, Stockholm, Sweden). The technical features of the oven were 220 V, 50 Hz and 1,450 W and the frequency of 2,450 Hz. The size of the oven was 520 × 440 × 335 mm and its rotating glass plate diameter was 315 mm. The effect of microwave power on the drying process of OA leaves was investigated at a load of 40 g. The OA leaves was dried in the microwave dryer at different microwave output setting of 450 (50% setting), 720 (80% setting) and 900 W (100% setting). Weight losses were measured at every 20 second intervals in each power of microwave dryer through a digital balance with an accuracy of 0.01 g and the drying data were recorded. The drying was terminated when the moisture content of the sample was reduced to certain moisture content when water activity (a_w) or RH_e was equal to 0.6. Three replicates were performed for each treatment.

Drying data in terms of moisture ratio (MR) which was simplified to M/M_o instead of the $(M- M_e)/(M_o-M_e)$ because it was suitable to represent the drying characteristics of food which was very low equilibrium moisture content (EMC) or EMC approach to zero [10]. Drying time were fitted by four thin layer drying models, namely Henderson and Pabis, Modified Page, Modified Zero and Three parameter models (equations (1)-(4) in Table 1), to find a suitable model and describe drying characteristics of the OA leaves. Effective moisture diffusivities (D_{eff}) (equation (5)) and activation energies (E_a) (equations (6) and (7)) were operated by nonlinear regression technique using the SPSS 19.0 for Window (SPSS, Inc., Chicago, IL). Three statistical parameters: coefficient of determination (R^2), standard error of estimate (SEE) and root mean square error (RMSE) were used to test the goodness of fit for each model.

$$SEE = \sqrt{\frac{\sum_{i=1}^{N}(MR_{pre,i} - \overline{MR}_{exp,i})^2}{d.f}} \tag{8}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \tag{9}$$

2.3. Color Measurement

The color of fresh and dried (vacuum blanched and unblanched) OA leaves was determined before and after drying using Hunter Lab (Ultra Scan Xe U3115, Color Global Co., Virginia, USA). The color was measured in terms of L*, a*, and b* values. The L* represented the lightness or darkness of the object and it was measured on a scale of 0 to 100. The L* value of 100 represented white and L* of 0 represented black. The a* represented redness (+) or greenness (-). The b* value represented yellowness (+) or blueness (-).

The total color difference (ΔE*) was the parameter considered for the overall color difference evaluation, between a dried sample and the fresh OA leaves as shown in equation [10].

$$\Delta E^* = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \tag{10}$$

Fresh OA leaves were used as the reference and a larger ΔE* denoted greater color difference from the reference material.

2.4. Microstructure Analysis

The microstructures analysis of dried OA leaves was proposed using scanning electron microscopy (SEM) (S-3000N, Hitachi, Japan). Dried OA leaves were cut into 10 x 10 mm slices. Samples were mounted onto aluminum specimen stubs using a mixture of two-component epoxy and water-based conductive graphite adhesive. The samples were reviewed at 20.0 kV in the SEM with a magnification of x 500, spatial resolution of 100 micrometer. The changes in cell dimensions and shape during drying were pictorially visualized by photographing.

2.5. Extraction

The extracts were prepared from the dried OA leaves (0.2 g) or fresh OA leaves (1 g). The OA leaves were extracted for 4 h with 10 mL of chloroform for Sinensetin (SEN) and Eupatorin (EUP) content and 50% methanol for total phenolics and antioxidant activity at 40 °C in a water bath. The mixture was filtered through a filter paper (Whatman No.1).

2.6. Total Phenolics (TPC)

The extract solutions (200 µL) were added in a test tube and 0.2 mL of Folin–Ciocalteu reagent were added and mixed thoroughly. After 4 min, 1 mL of 15% Na_2CO_3 was added, and then the mixture was allowed to stand for 2 h at 30 °C. The absorbance was measured at 760 nm using a spectrophotometer (Lambda 25, Perkin-Elmer, Germany). The total phenolics of the extracts was calculated and expressed as gallic acid equivalents per gram of dry basis (mg GAE/g d.b) based on the gallic acid standard curve. Each sample was measured in triplicate and averaged.

2.7. Antioxidant Activity (AOA)

The methanolic solution (2 mL) of 1,1-diphenyl-2-picrylhydrazyl (DPPH) (0.1 mM) were mixed with 200 µL of samples of the OA leaves extract (0.05 mg/ml), made up with methanol to a final volume of 3 mL. After 60 min standing, the absorbance of the mixture was measured at 517 nm against methanol as a blank using a spectrophotometer (Lambda 25, Perkin-Elmer, Germany). The radical-scavenging activities (% inhibition) of the tested samples were evaluated by comparison with a control (2 mL DPPH solution and 1 mL of methanol). Each sample was measured in triplicate and averaged.

2.8. Sinensetin (SEN) and Eupatorin (EUP) content

The composition of solvents and the isocratic conditions were prepared using the modified method of Akowuah *et al.* [7]. The HPLC analysis was performed with Waters 717 plus autosampler (WatersTM), Waters 600 controller (WatersTM), Waters in-line degasser (WatersTM), Waters 486 tunable absorbance detector (WatersTM), Waters 410 differential refractometer (WatersTM), and a Symmetry C18 column (250×4.6 mm i.d., 5mm; Waters) at 25°C. A modified mobile phase consisted of a mixed solution of methanol:water:tetrahydrofuran (v/v 45:50:5) was used. The flow rate was 1 mL/min; Ultraviolet detector was at 340 nm, and the injection volume was 20 µL. The SEN and EUP were identified by comparing their HPLC retention times with those of authentic samples as standards.

2.9. Statistical Treatment

A completely randomized design 2x3 factorials was used to study the main factors of the blanching pretreatments: unblanched and vacuum blanched pretreatments and microwave power levels: 450 W, 720 W and 900 W and their interaction. Three replications were used to determine each drying treatment. The SPSS 19.0 for Windows (SPSS, Inc., Chicago, IL) was used to calculate analysis of variance (ANOVA). Duncan's multiple range tests was used to compare the significance of treatment means at a 95% confidence interval.

3. Results and Discussion

3.1. Modeling of Microwave Drying Characteristics of OA Leaves

The unblanched and vacuum blanched OA leaves were dried in the microwave dryer (MWD) at 450, 720 and 900 W. The influence of the vacuum blanching pretreatment and microwave powers were investigated. The moisture ratios of the unblanched and vacuum blanched OA leaves predicted from the Three parameter model compared with the observed experimental data are illustrated in Figures 1 and 2, respectively. The experimental

data of all treatments were in good agreement with the model prediction. The drying constant (K), drying exponent (N), constant (A) and statistical analysis values of the drying models of unblanched and vacuum blanched OA leaves are given in Table 2. The drying data were fitted to four thin layer drying models: Modified Page, Henderson and Pabis, Modified Zero and Three parameter models (Table 1). The suitability of the mathematical model was based on the R^2, SEE and RMSE. The most suitable model describing the thin layer drying characteristics of the unblanched and vacuum blanched OA leaves was chosen as the one with the lowest SEE and RMSE and the highest R^2 (Table 2). Therefore, the Three parameter model was the best model to describe the drying curves of the unblanched and vacuum blanched OA leaves having the highest R^2 value and the lowest SEE and RMSE values in the microwave levels of the study. The Three parameter model was the best model to describe the drying curves of the vacuum blanched and unblanched OA leaves because the exponent (N) was added at drying constant and drying time in order to increase the dependence of microwave output. In addition, the constant (A) was still added to an exponential term in order to describe experimental data affected by the diffusion of moisture.

Table 2 The drying constants (K), N and A of unblanched and vacuum blanched OA leaves from various microwave powers

Models		Microwave power (W)					
		Unblanched			Vacuum blanched		
		450	720	900	450	720	900
Modified Page	K (min^{-1})	0.0826	0.2556	0.4044	0.3450	0.7251	0.8053
	N	0.7417	0.8005	0.9558	1.5048	1.1271	1.2112
	R^2	0.9982	0.9732	0.9904	0.9812	0.9977	0.9828
	SEE	0.0068	0.0347	0.0238	0.0442	0.0150	0.0436
	RMSE	0.0067	0.0336	0.0227	0.0430	0.0144	0.0414
Henderson and Pabis	K (min^{-1})	0.0856	0.2586	0.4075	0.3824	0.7562	0.8497
	A	0.9317	0.9622	0.9981	1.0742	1.0257	1.0259
	R^2	0.9839	0.9563	0.9896	0.9466	0.9947	0.9743
	SEE	0.0204	0.0444	0.0248	0.0744	0.0230	0.0533
	RMSE	0.0201	0.0429	0.0236	0.0724	0.0220	0.0506
Modified Zero	K (min^{-1})	0.0984	0.2748	0.4086	0.3556	0.7373	0.8289
	R^2	0.9514	0.9506	0.9896	0.9390	0.9937	0.9733
	SEE	0.0355	0.0472	0.0248	0.0796	0.0250	0.0544
	RMSE	0.0350	0.0456	0.0236	0.0774	0.0239	0.0516
Three parameter	K ($min^{-1)}$	0.0827	0.2641	0.4099	0.3187	0.7209	0.7798
	N	1.0011	1.0272	1.0127	0.9107	0.9948	0.9708
	A	0.7396	0.7636	0.9345	1.8319	1.135	1.2685
	R^2	0.9982	0.9747	0.9907	0.9888	0.9978	0.9837
	SEE	0.0067	0.0326	0.0224	0.0341	0.0149	0.0425
	RMSE	0.0066	0.0316	0.0214	0.0332	0.0143	0.0403

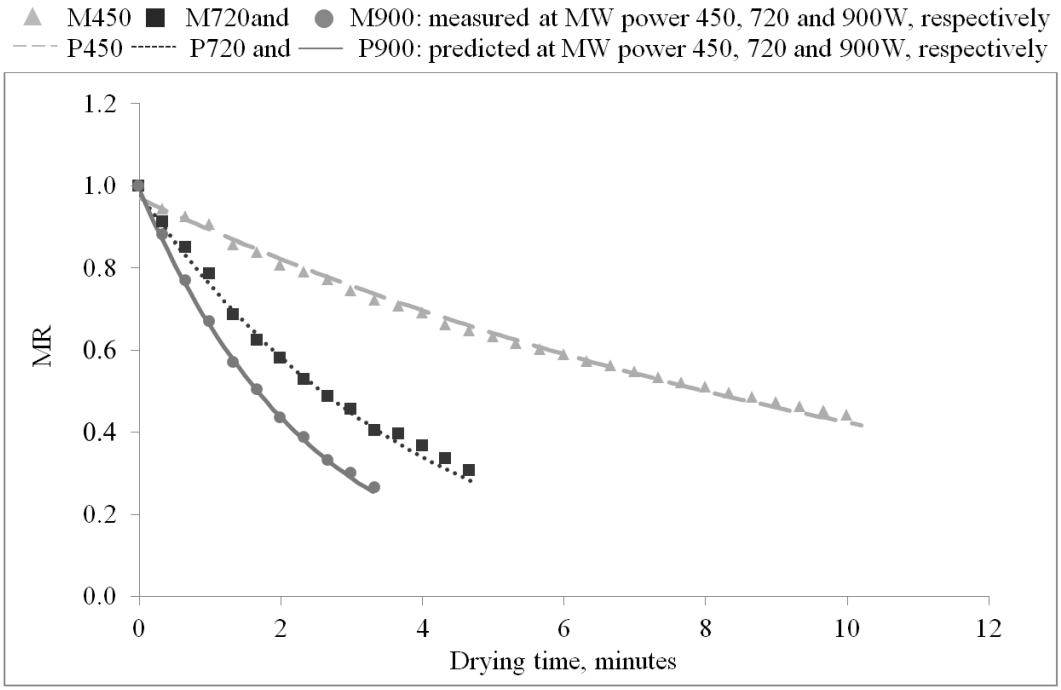

Figure 1 Moisture ratios of unblanched OA leaves predicted from the Three parameter model compared with the observed experimental data from MWD

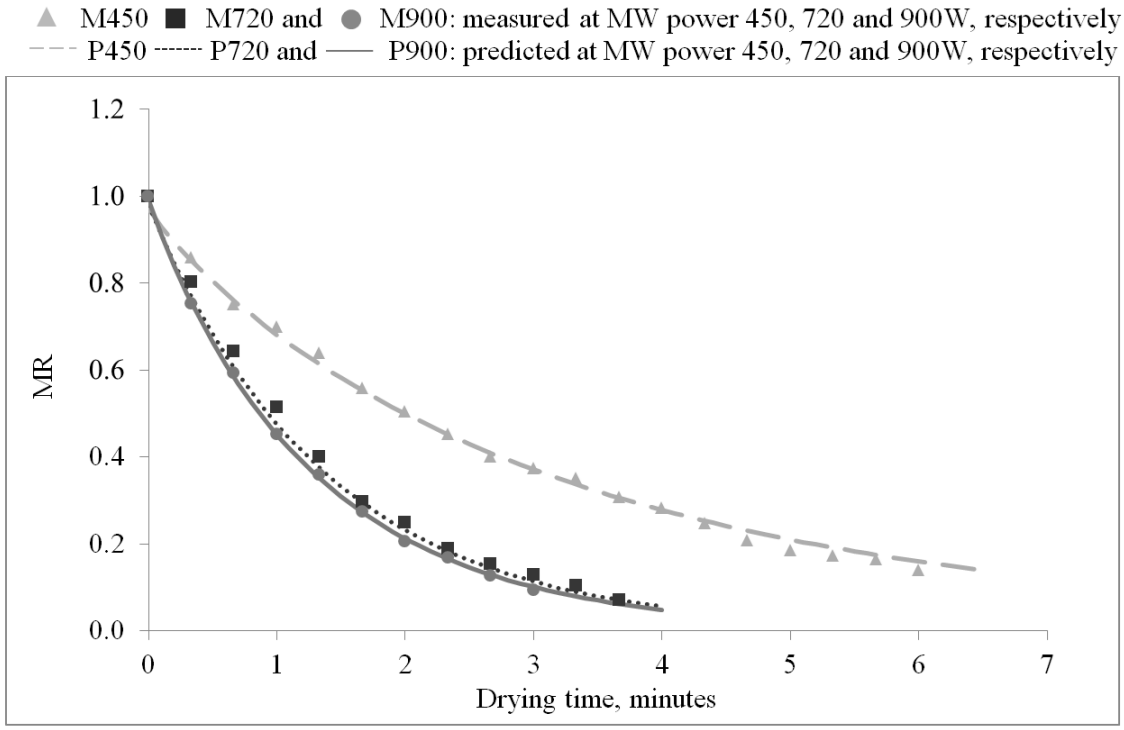

Figure 2 Moisture ratios of vacuum blanched OA leaves predicted from the Three parameter model compared with the observed experimental data from MW

The drying constants (K) of the unblanched and vacuum blanched dried OA leaves were increased from 0.0827 to 0.4099 min^{-1} and 0.3187 to 0.7798 min^{-1}, respectively with increasing microwave power levels (Table 2). It was found that drying constants were increased with the increase of microwave power levels because high microwave power level also provided high molecule rotation; therefore, it could generate more heat and fast remove water than low microwave power level. Increase microwave levels from 450 W to 900 W could reduce drying times for 66.7% and 50.0% for the unblanched and vacuum blanched, respectively. The shortest drying time of 3 min was obtained from the vacuum blanched of dried OA leaves using MWD at 900 W (Table 3).

Table 3 Effective moisture diffusivity (D_{eff}) and drying time of dried OA leaves

Treatment	Microwave Power (W)	D_{eff} (m^2/s)	Drying time (min)	R^2	SEE (m^2/s)	RMSE (m^2/s)
Unblanched	450	1.32E-09	10.0	0.874	0.057	0.056
	720	4.10E-09	4.7	0.859	0.080	0.077
	900	6.30E-09	3.3	0.868	0.088	0.084
Vacuum blanched	450	6.12E-09	6.0	0.845	0.127	0.123
	720	1.28E-08	3.7	0.926	0.086	0.082
	900	1.45E-08	3.0	0.901	0.105	0.099

The effective moisture diffusivities (D_{eff}) of the unblanched and vacuum blanched OA leaves were in the range from 1.32E-9 to 6.30E-9 m^2/s and 6.12E-9 to 1.45E-8 m^2/s, respectively (Table 3). The effective moisture diffusivities for the vacuum blanched OA leaves were higher than unblanched OA leaves. The effective moisture diffusivities were increased substantially due to vacuum blanching treatment prior to drying and microwave power levels. The vacuum blanching treatment likely caused microstructural changes to the exterior surface of the OA leaves, leading to increase rate of water loss, thereby improving the effective moisture diffusivities. Özbek and Dadali [11] reported that the effective moisture diffusivities of mint leaves undergoing microwave drying were varied from 3.982E-11 to 2.073E-10 m^2/s which were less than the D_{eff} of this work. The effective moisture diffusivities in food materials were in the range from 10E-10 to 10E-9 m^2/s [12]. A similar result of D_{eff} was found to correspond well with existing in the literature for olive leaves: 0.295 E-9 to 3.60 E-9 m^2/s) [13].

Activation energy (Ea) may also be defined as the minimum energy required to starting a chemical reaction. The activation energy of the microwave drying could be calculated by using equation (6) and (7). The values of the activation energy of the unblanched and vacuum blanched OA leaves obtained from equation (6) were 59.4695 and 30.7528 W/g and the Ea from equation (7) were 57.9795 and 30.1063 W/g, respectively (Table 4). The values of the activation energy of this work were higher than the reported values of 5.54 W/g for okra [14], 13.6 W/g for pandanus leaves [15], 12.284 for mint leaves [11], 16.675 W/g and 24.222 W/g for sweet and sour pomegranate [16], respectively. The activation energy of dried potato slices using microwave dryer was estimated to be 10.91 W/g [17] which was lower than the Ea of this work due to the particular variety of agricultural products. The values of the activation energy of dried OA leaves which calculated from equation (6) were similar to the values of the activation energy which were calculated from equation (7). The vacuum blanched OA leaves showed lower activation energy than unblanched OA leaves because the vacuum blanched treatment help reduce wax on the surface of leaf and increase permeability of cell wall [18]; therefore, the vacuum blanched samples required lower energy to evaporate the water inside the product than unblanched sample.

Table 4 Activation energy (Ea) predicted from drying constant (K) and effective moisture diffusivity (D_{eff}) of dried OA leaves

Treatment	Unblanched	Vacuum blanched
K_o (min^{-1})	2.1246	1.9193
Ea (W/g)	59.4695	30.7528
R^2	0.9989	0.9528
SEE (min^{-1})	0.0053	0.0545
RMSE (min^{-1})	0.0044	0.0445
D_o (m^2/s)	3.13E-08	3.44E-08
Ea (W/g)	57.9795	30.1063
R^2	0.9988	0.9784
SEE (m^2/s)	8.69E-11	6.50E-10
RMSE (m^2/s)	7.09E-11	5.31E-10

3.2. Color Values

The color values of microwave drying at 450, 720 and 900 W are shown in Table 5. The a* and b* of dried OA leaves using MWD at 450, 720 and 900 W, which indicated red and yellow color, respectively were not significantly different ($p>0.05$).

Total color difference (ΔE*) was the parameter considered for the overall color difference evaluation between the dried sample and the fresh OA leaves. The low ΔE* indicated less color change in the dried OA leaves compared with fresh leaves. The lowest ΔE* were found at 720 and 900 W in both conditions (vacuum blanched

and unblanched) ($p<0.05$). It means that the both conditions of OA leaves dried using MWD at 720 and 900 W had less color change than 450 W due to shorter drying times (Table 3). The results were similar to the study of Rayaguru and Routray [15] who reported that the color quality of *pandanus amaryllifolius* leaves dried by MWD at 540 W were higher than 180 W.

3.3. Scanning Electron Micrograph

The scanning electron microscopy (SEM) was used to investigate the fresh and dried (vacuum blanched and unblanched) OA leaf structures. The pictorial visualization of the unblanched and vacuum blanched samples by photographing is shown in Figure 3. Pretreatment with vacuum blanching before drying provided less cell wall damage than unblanched treatment because vacuum blanching could soften the cell walls and could reduce drying time (Table 3). In addition, cell wall damage and tissue collapse of the dried OA leaves from microwave drying at 900 W (Figure 3(b, d)) were less than the microwave drying at 450 (Figure 3(a, c)). Vacuum blanched and dried OA leaves using MWD at 900 W (Figure 3d) had the most porous and least cell wall damage than others treatments. The results of this work agreed well with Potisate *et al.* [19] who reported that increasing microwave power levels helped prevent shrinkage and case hardening in dried Moringa leaves. The less cell wall damage in the dried samples at 900 W may be because of the short drying time (Table 3). The decomposition and conversion of pectin substances during drying were the cause of microstructural changes in the OA leaves after drying. Some tissue, a cellular organizational level between cells and a complete organ, expansion from internal water vapor in food generated heat from rotation of the water molecules.

Table 5 The color values of dried OA leaves from microwave drying

Treatment	MicrowavePower (W)	L*	a*	b*	ΔE*
Unblanched	450	45.12 ± 0.17^{ab}	-6.08 ± 2.12^{a}	9.90 ± 0.95^{a}	47.27 ± 4.37^{a}
	720	42.36 ± 1.23^{bc}	-0.54 ± 0.29^{a}	4.90 ± 2.71^{a}	31.65 ± 4.47^{bc}
	900	44.83 ± 1.99^{abc}	-3.91 ± 2.05^{a}	7.73 ± 2.74^{a}	31.62 ± 14.82^{bc}
Vacuum blanched	450	45.40 ± 2.20^{ab}	-4.93 ± 3.81^{a}	9.03 ± 3.03^{a}	39.60 ± 8.65^{ab}
	720	44.78 ± 0.80^{abc}	-4.67 ± 0.29^{a}	7.37 ± 0.78^{a}	24.84 ± 4.81^{bc}
	900	44.46 ± 0.35^{bc}	-4.47 ± 0.07^{a}	7.75 ± 1.08^{a}	23.21 ± 1.79^{c}

[a,b,c,] Different small letters in the same column mean that values are significantly different ($p \leq 0.05$).

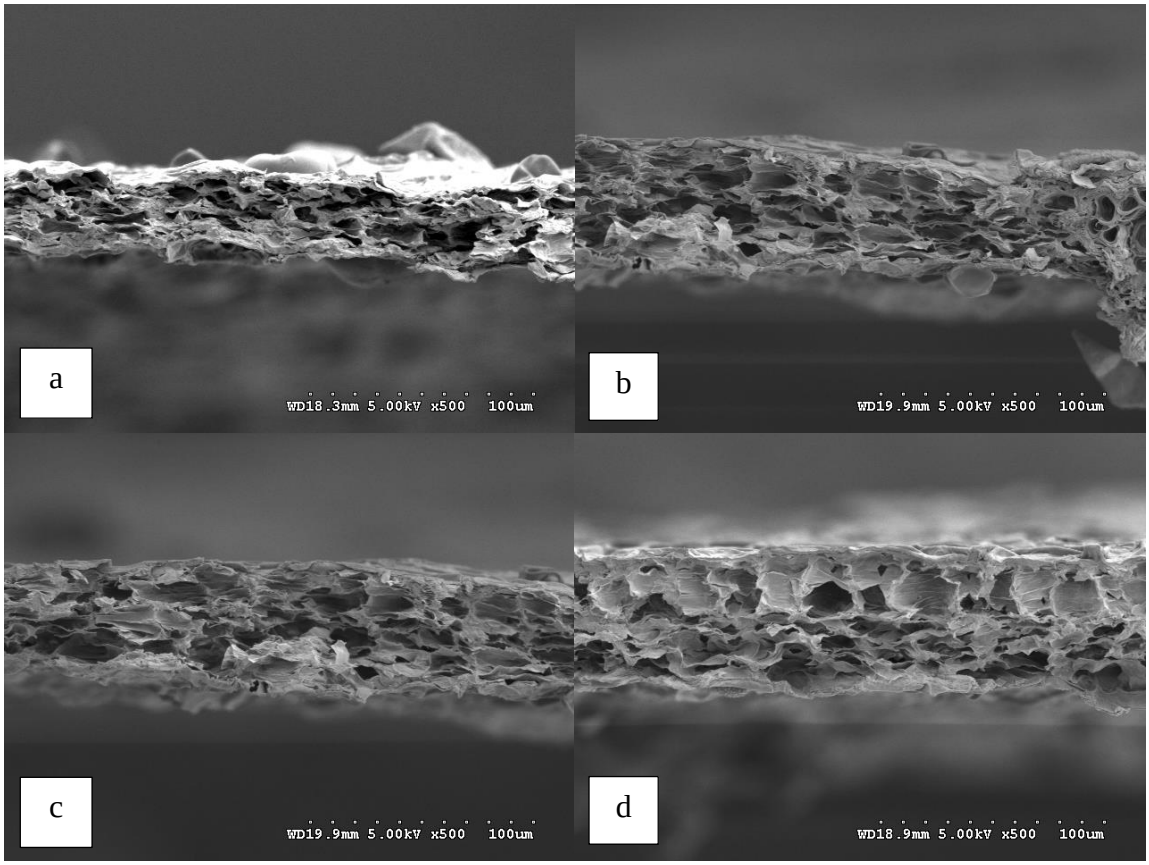

Figure 3 Scanning electron micrographs of OA leaves (a) unblanched microwave dried at 450W, (b) unblanched microwave dried at 900W, (c) vacuum blanched microwave dried at 450W, (d) vacuum blanched microwave dried at 900W

Table 6 Total phenolics, % inhibition and bioactive compounds of microwave dried OA leaves

Treatment	Microwave Power (W)	Total phenolics (mg GAE/g d.b.)	%inhibition	Sinensetin (µg /g d.b.)	Eupatorin (µg /g d.b.)
Unblanched	450	4.73±0.30^{f}	30.62±0.96^{c}	0.28±0.05^{d}	0.52±0.00^{e}
	720	5.58±0.08^{e}	31.04±0.09^{c}	0.29±0.00^{d}	0.61±0.02^{d}
	900	6.45±0.08^{d}	39.44±0.91^{b}	0.33±0.01^{c}	0.69±0.01^{c}
Vacuum blanched	450	12.93±0.27^{c}	82.73±1.22^{a}	0.42±0.01^{b}	0.83±0.01^{b}
	720	14.74±0.11^{b}	82.57±1.70^{a}	0.52±0.02^{a}	0.81±0.01^{b}
	900	15.13±0.10^{a}	84.50±1.53^{a}	0.53±0.00^{a}	0.90±0.01^{a}

^{a,b,c,} Different small letters in the same column mean that values are significantly different ($p \leq 0.05$)

3.4. Total Phenolics and % Inhibition

Table 6 presents the total phenolics and % inhibition of vacuum blanched and unblanched OA leaves from microwave drying. The vacuum blanched dried OA leaves by microwave drying at 900 W gave the highest total phenolics followed by the microwave drying at 720 and 450 W ($p<0.05$) and the vacuum blanched condition gave higher total phenolics than unblanched condition in all of power levels. The result indicated that the total phenolics were significantly increased with increasing microwave powers. In addition, the vacuum blanched condition significantly provided higher total phenolics than unblanched condition. Some other studies have also reported that the phenolic content was increased after heat or radiation treatment of the plant materials [20, 21, 22, 23, 24].

Similarly, Ballard *et al.* [25] reported that total phenolics were increased when the microwave power was increased from 10% to 90% setting.

The antioxidant activity of the dried OA leaves was increased with increasing microwave power. The antioxidant activity of the dried OA leaves from the microwave drying was in the range from 30.62 to 84.50 %. For unblanched treatment, the antioxidant activities of the dried OA leaves at 900 W were higher than the microwave drying at 720 and 450 W. The vacuum blanched condition gave higher antioxidant activity than unblanched condition in all of power levels (Table 6). The increase in the total phenolics could be the reason of higher antioxidant activity. Free phenolic compounds have been shown to have greater antioxidant effect than the bound forms [26]. The increase in antioxidant activity with the microwave power could be attributed to the increase in free fraction of phenolic compounds [27]. Pretreatment with vacuum blanching caused an increase the antioxidant potential of herb fruit and vegetables or enhanced it due to enlargement of antioxidant properties of naturally compounds because the higher total phenolics measured the higher yield of antioxidant activity; this was probable due to the combined effect of the phenolic compounds and their high hydrogen atom donating abilities. [28].

3.5. Bioactive Compounds

Sinensetin and eupatorin are two of the major bioactive compounds which found in the OA leaves. Sinensetin could inhibit a diuretic activity in rats after intravenous administration [29]. Eupatorin acts as an antiproliferative in cells which also functions as an anti-inflammatory [30].

The statistical analysis of the sinensetin and eupatorin contents in the dried OA leaves from the microwave drying is shown in Table 6. The sinensetin and eupatorin contents of the microwave drying were increased with increase of microwave power. The vacuum blanched OA leaves from the microwave drying at 720 and 900 W provided the highest sinensetin (0.52 and 0.53 µg /g d.b.), respectively. In addition, the vacuum blanched OA leaves from the microwave drying at 900 W provided the highest eupatorin (0.90 µg /g d.b.). The vacuum blanched and dried OA leaves using MWD at 900 W could retain the sinensetin and eupatorin by 37.7% and 23.3% respectively compared with unblanched treatment. The results showed that pretreatment with vacuum blanching and high microwave output gave higher sinensetin and eupatorin contents than unblanched treatment because the pretreatment with vacuum blanching and high microwave output could reduce drying time (Table 3) having less cell damage and retain bioactive compounds. The results of this work agreed with some microwave drying studies which revealed that high microwave output provided the highest bioactive compound of dried *Moringa oleifera* (Lam.) leaves [10] and dried sour cherries [31].

4. Conclusions

The vacuum blanched and unblanched OA leaves were dried in the microwave dryer at 450, 720 and 900 W. The Three parameter model was the best model to describe the drying curves of the OA leaves due to the highest R^2 and lowest SEE and RMSE for both conditions (vacuum blanched and unblanched). Increase microwave output from 450 W to 900 W could reduce drying times for 66.7% and 50.0% for unblanched and vacuum blanched, respectively. The effective moisture diffusivities of the OA leaves using the MWD were in the range from 1.32E-9 to 1.45E-8 m^2/s and increased with increasing microwave output and pretreatment with vacuum blanching. The vacuum blanched OA leaves showed lower activation energy than unblanched OA leaves. The dried OA leaves using the MWD at 720 and 900 W in both treatments (vacuum blanched and unblanched) provided the lowest total color difference. The vacuum blanched and dried OA leaves using MWD at 900 W had the most porous and least cell damage than other treatments. The vacuum blanched and dried OA leaves using the MWD at 900 W provided the highest total phenolics and eupatorin. The vacuum blanched OA leaves from the microwave drying at 720 and 900 W provided the highest sinensetin. All vacuum blanched treatments gave the highest antioxidant activity. The vacuum blanched and dried using the MWD at 900 W could retain the sinensetin and eupatorin by 37.7% and 23.3% respectively compared with unblanched treatment. Therefore, the vacuum blanched and dried OA leaves using the MWD at 900 W is a possible drying method for the OA leaves in food industry or small and medium enterprises (SMEs) processing due to the highest total phenolics, antioxidant activity, sinensetin and eupatorin.

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