Microwave-drying of Scent Leaf (Ocimum gratissimum)

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ABSTRACT: The influence of microwave-drying method of scent leaves was experimentally investigated over microwave power outputs (90 - 900 W). Scent leaves were dried in thin-layer using microwave oven. Consequently, the drying process time decreased with increased microwave power from 22 to 4.5 minutes to effectively dry the samples. The Midilli et al. model among the models used gave the best description of the drying process for all the microwave power output conditions using nonlinear regression fitting method. The effective moisture diffusivity coefficients varied from $2.73 \times 10^{-10}$ to $1.82 \times 10^{-9}$ m$^2$/s across the microwave output power. The obtained Arrhenius-type calculated pre-exponential factor and activation energy values of scent leaves were $1.0577 \times 10^{-9}$ m$^2$/s and 31.801 W/g, respectively. The microwave drying study of scent leaf is relevant to good health and life in the developing world, where many cannot access balanced diet meals. This study practically provides knowledge base for researchers, entrepreneurs food industries and policy makers with the possibilities of accessing fast, hygienic, easy-to-transport and packaged, energy-saving and safe approach to the produce’s processing and preservation, thus providing supplements and by-products of the leaves for people’s diet and wellbeing, thereby ensuring contribution toward food security.

Keywords: Thin-layer, scent leaf, microwave-drying, modeling, activation energy, moisture diffusivity.

INTRODUCTION

Man consumes plants for several reasons but primarily for their nutritional and medicinal values. Plant parts are considered valid when consumed as food or used as medicine; based on this function they are differentiated from one another.

Scent leaves (Ocimum gratissimum) is an aromatic medicinal plant. It is a perennial herb of about 1-3 m tall with erect stem and round quadrangular shape belonging to the Labiatae family in the tropics of Africa and Asia. It is a well-known plant used for medicine and processed eatable vegetable. Its highly perishability and non-availability during drying season makes its preservation highly desirable, which requires processing treatments to avoid post-harvest losses. The leaves are oftentimes referred to as Basil fever plant or tea bush and in Nigeria, Daidoya ta gida (Hausa), Nehonwu (Igbo), Tanmotswangi-wawagi (Nupe) and Efinrin (Yoruba) (Abdullahi et al., 2003). They are typically subjected to sun-drying as a mean of preservation, before its final consumption in close likeness of freshly harvested vegetables in soups. As a medicinal plant, its contained bioactive compounds and others compounds such as alkaloids, carbon compounds, glycosides, essential oils, fatty oils, resins, mucilage, tannins and gums enlist it as a precursor for drugs synthesis of useful and

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therapeutic use (Pandey, 1980; Sofowora, 1993).
It is low phenolic contents possess antimicrobial and antifungal effect and thus used in disinfections. It is used to treat several maladies - bacterial infections, diabetes, pain and liver damage, strains of E. coli, dysentery and typhoid. In animals, it is used to handle divers veterinary problems, killing worms in goats and to increase libido in laboratory mice (Edeoga et al., 2005). Its oil possesses therapeutic, antiseptic or bactericidal properties for preventing several infections. It is used in the management of baby’s cord (Idris et al., 2011). Also, the oil is an effective mosquito repellent and an analgesic.

The appreciable amount of basic food components - protein, fats carbohydrates and fibre; and mineral elements - calcium, potassium, magnesium, nitrogen are required for cell (worn out) repair, strong and healthy bones and teeth, red blood cells building, and body mechanisms) make it desirable in human nutrition in it (WHO, 1996). The high contents of these elements make it alternative sources of calcium and potassium in the diet. In dried and powdery form, it is used in bakery products, confectionary, ice creams, vinegar, meat and flavour products, soup (Özcan and Chalchat, 2002; Di Cesare et al., 2003; Özcan et al., 2005). The contained flavonoids, alkaloids content and tannins components were assumed for its peculiar scent, bitter taste, and astringent tea flavour respectively.
The primary purpose of removing water from materials (drying) in food processing is to allow for minimized packaging requirements, longer storage shelf life, reduced transportation weights, all year-round preservation (periodical food) and availability for consumers (Maroulis and Saravacos, 2003). The quality and quantity of an effectively dried food product determine its storability over a specific period, that though depend on the product’s nature. Through convective and conductive drying mechanisms, food’s moisture content is reduced and its shelf-life increased (Jiang et al., 2015; Bennamoun et al., 2016). Effective drying could be achieved (Bennamoun, Chen, & Afzal, 2016) through solar drying, mechanical drying, oven drying, air drying methods. Drying process impacts vital changes (structural, biological and physicochemical) in the food material, which eventually affect the final product quality and properties - physical, chemical, flavour, taste, hardness spoilage, viscosity, microbial activities, aroma (Barbosa-Canovas and Vega-Mercado, 1996).
Traditionally, leafy vegetables are sun-dried or hot air-dried, but the former is limited with long process time, high contamination, inconsistent attainment of quality standards and inability to handle large sample volume (Soysal, 2004). The latter is limited with low energy efficiency, high-energy consumption, long process time consequent to low thermal conductivity of food materials in the fall-rate period; with limited heat transfer to the food core and direct heat penetration movement from heating source into the material, thereby destroying some material components and properties (Maskan, 2000). Microwave processing technologies and methods have been extensively used in the food industry due to its significant reduction in cooking time and energy consumption. Microwave drying, heating and sterilizing play a significant role in food quality and safety control. Microwave mechanism dries via dielectric heating due to polarization effect at a frequency range of 300 MHz – 300 GHz with a wavelength of 1 m – 1 mm. During the process, food material absorbs microwaves (energy-carrying waves, which are radiated from a source in all directions) and converts it to heat by polar molecules - water and a food component. Consequent to the heat production, the water molecules evaporate and the material dries (Decareau, 1985). These penetrate into the material and heats the material without any thermal gradient therefore, enhancing drying efficiency (Jiang et al., 2016; Zhang et al., 2007). Microwave drying provides an alternative approach to drying with consistent, uniform
radiation energy and high thermal conduction flow pattern to the food core, reduced process time, prevention against food enzymatic decomposition, space utilisation, sanitation, energy conservation, process control precision and quick process initiation and shut down responses (Decareau 1985, 1992; Soysal and Öztekin 2001; Feng et al., 2012; Zhang et al., 2006) with wide range of application on food, crops, wood, medicinal and herbal products. Its place in the drying of food materials such as apple (Wu et al., 2014), cabbage (Duan et al., 2013), instant mixed vegetable soup (Wang et al., 2010); potato (Wang et al., 2011; Wang et al., 2013), stem lettuce slices (Wang et al., 2013), potato chips (Su et al., 2015) and sea cucumber (Duan et al., 2007) have been investigated.

The formalization of the process becomes important to obtain quality product in the practice and monitoring of the drying process (Huie, 2002). To achieve this, the models are used to establish the relations between moisture content and drying time to describe the process. This study aimed to describe the drying characteristics of scent leaf, evaluate the microwave power output variation on the drying characteristics of the scent leaves, and model the drying process using mathematical models.

MATERIALS AND METHOD

Materials
Fresh scent leaves samples were obtained from a local farm in Akure, a South-western city of Nigeria. The samples were cleaned, washed, stored in a low-density plastic bags and kept in a refrigerator for a day to allow for equilibration of moisture. Prior to the commencement of the drying experiments, the samples were removed from the refrigerator and the leaves were de-stalked from the stem. The initial moisture content of the samples was determined by via air-oven drying method described by the AOAC moisture content determination method (AOAC 1990). Three 20 g of samples were dried in an oven (Laboratory Oven - DH 250) at 105 °C for 24 h. The initial moisture content of the samples was 86.61 (g water/g wet matter); with less than 5 % measurement reproducibility range.

Microwave drying experiment
A microwave oven (Sanyo EM-G4753AW, UK) with a technical specification of ~230 V, 50 Hz and 2650 W and a frequency of 2450 MHz (a wavelength of 12.24 cm) was used for the drying process. The oven was equipped with 90, 180, 360, 540, 600, 720 and 900 W microwave power outputs. It has a drying cavity with volume 340 x 220 x 320 mm³ and a 300 mm diameter rotating glass plate at its base. The microwave output powers and operation time were controlled via an embedded digital control.

Fresh scent leaves samples were uniformly distributed in a thin layer on the rotating glass of the microwave at the centre of the oven with thickness, 0.50 ± 0.05 mm. The moisture loss in the samples was measured periodically (interval of 30 s during the drying process to determine the drying kinetics) by weighing it on the digital balance with a precision of 0.01 g. The experiments were conducted in replicates of each treatment according to the respective microwave power output. The drying process was continued with the applied microwave power until there was constant reduction in the mass of the sample to a corresponding moisture content level of about 0.01 g water/g wet matter. The weighing processes were done in a short time and the average data of the results were presented with less than 5 % range of experimental reproducibility. The moisture content per time of the sample during the process was calculated using equation 1.

\[ M_t = \frac{m_w - m_d}{m_d} \]  

where \( M_t \) is the moisture content (g water/g dry matter), \( m_w \) the wet mass of sample at a time (g), and \( m_d \) is the corresponding dry mass of the sample (g).
Mathematical modeling of drying curves

The experimental data obtained from the drying microwave power outputs were expressed in terms moisture ratio, drying time and drying rate. The moisture ratio (MR) and the drying rate (DR) of the scent leaves were determined using the equations 2 and 3 (Midilli et al., 2007):

\[
MR = \frac{M_t - M_{\infty}}{M_0 - M_{\infty}} \quad (2)
\]

\[
Drying\ rate = \frac{M_{t+dt} - M_t}{dt} \quad (3)
\]

For microwave drying, the equilibrium moisture content (\(M_e\)) was assumed to be zero, therefore the equation simplified then become (Maskan, 2000; Soysal, 2004; Akpinar, 2006; Dadali et al., 2007a, c)

\[
MR = \frac{M_t}{M_0} \quad (4)
\]

where \(M_t\) is the moisture content at any given time (g water/g dry matter), \(M_0\) is the initial moisture content (g water/g dry matter), \(M_{\infty}\) is the equilibrium moisture content (g water/g dry matter), \(M_{t+dt}\) is the moisture content at \(t + dt\) (g water/g dry base) and \(t\) is drying time (min).

Determination of moisture diffusivity

The intrinsic mass transfer property of moisture within a food material defines the food effective moisture diffusivity. It was assumed that Fick’s second diffusion equation presented the main mass-diffusive mechanism to transfer the water to surface during drying process as expressed in equation (5) (Dincer and Dost, 1995; Dadali et al., 2007b; Wang et al., 2007):

\[
\Delta M = D_{eff} \Delta^2 M \Delta t \quad (5)
\]

The dearth of information on the mechanism of moisture mass transfer during drying and complexity of the process paved way for the use effective moisture diffusivity instead of the effect of its composition, moisture content, temperature and porosity of the material (Abe and Afzal 1997). The scent leaves were assumed to be a slab for the Fick’s diffusion equation solution with thickness (0.50 ± 0.05 mm). The moisture movement by thermal gradient within the thin slab was considered negligible, the moisture transfer was considered as a one-dimensional diffusion process in the upward direction from the base of the sample to its top surface. It was also assumed that the sample presents a uniform initial moisture content for diffusion analysis, the moisture movement is diffusive in pattern, and the samples shrinkage are negligible. Therefore, the analytical solution of the diffusion equation (5) for an infinite slab with constant diffusivity if appropriate initial and boundary conditions were applied can be used to determine the moisture ratio in equation (6) (Celma et al., 2008 and Crank, 1975).

\[
MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp \left( \frac{(2n+1)^2 \pi^2 D_{eff} t}{4L^2} \right) \quad (6)
\]

where \(D_{eff}\) is the effective diffusivity (m²/s), \(L\) is the half-thickness of the slab (m) and \(n\) is the number of terms of the series taken into consideration.

For long drying times, only the first term \((n=0)\) in the series expansion of the above equation gave good estimate of the solution with equation (6) simplified to the first term of the series (Senadeera et al., 2003). Taking natural logarithm of both sides, we have equation (7):

\[
\ln(MR) = \ln \left( \frac{8}{\pi^2} \right) - \frac{\pi^2 D_{eff} t}{4L^2} \quad (7)
\]

The diffusion coefficient for each microwave drying power was calculated using equation (7). The coefficient was determined by the plotting experimental data against drying time, and fitting a straight line to \(\ln(MR)\), the slope of the straight line was expressed as equation (8):

\[
slope(\emptyset) = \frac{\pi^2 D_{eff}}{4L^2} \quad (8)
\]

Therefore;

\[
D_{eff} = \frac{4L^2 \emptyset}{\pi^2} \quad (9)
\]
The use of equation (9) was based on constant moisture diffusivity assumption for each microwave power which predicted a linear behaviour for the dependence of logarithmic dimensionless moisture ratio on drying time. Consequently, the slope was regarded as first useful approximation to the value of the diffusivity.

Statistical analysis

The behaviour of the samples during the process was observed by plotting the moisture ratio against the drying time. The experimental data were fitted to seven thin-layer mathematical models (Table 1) to describe the process.

The numerical calculations of the data were done using the software packages STATISTICA 12 (StatSoft Inc., Tulsa, USA) and Excel 2016 (Microsoft Inc.). The models’ parameters were evaluated with the non-linear regression techniques of Marquardt-Levenberg until minimal error was achieved between experimental and calculated values.

The coefficient of determination, \( R^2 \); normalized root mean square error, NRMSE; sum of square of residuals, SSE and root mean square error, RMSE of the mathematical models were the statistical parameters calculated and used to evaluate the fitting of the models to experimental data. The higher values of the coefficient of determination \( R^2 \) and the lower values of the reduced normalized root mean square error \( (NRMSE) \), sum of square of residuals \( (SSE) \) and root mean square error \( (RMSE) \) were chosen for goodness of fit (Midilli et al., 2007). These parameters were calculated using equations (10) to (13):

\[
R^2 = \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i}) \sum_{i=1}^{N} (MR_{exp,i} - MR_{exp,i})}{\sqrt{\left[ \sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i}) \right] ^2}}
\]

\[
RMSE = \frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2}{N}
\]

\[
NRMSE = \frac{1}{\sqrt{N}} \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i})^2}{MR_{exp,max} - MR_{exp,min}}
\]

\[
SSE = \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2
\]

where \( MR_{exp,i} \) is the \( i \)th experimentally observed moisture ratio, \( MR_{pre,i} \) is the \( i \)th predicted moisture ratio, \( N \) is the number of observations, \( MR_{exp,max} \) is the maximum experimentally observed moisture ratio, and \( MR_{exp,min} \) is the minimum experimentally observed moisture ratio.

<table>
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<tr>
<th>Models</th>
<th>Equations</th>
<th>Reference</th>
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<tr>
<td>Lewis</td>
<td>( MR = e^{x p (-a t)} )</td>
<td>McMinn (2006)</td>
</tr>
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<td>Page</td>
<td>( MR = e^{x p (-a t b)} )</td>
<td>Kaleemullah and Kailappan, (2006)</td>
</tr>
<tr>
<td>Henderson and Pabis</td>
<td>( MR = b e^{p x} (-a t) )</td>
<td>Akpinar et al., (2004)</td>
</tr>
<tr>
<td>Two-term exp.</td>
<td>( MR = a e^{x p (-b t)} + (1 - a) e^{x p (-a b t)} )</td>
<td>Togrul and Pehlivan (2004)</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>( MR = c + a e^{x p (-b t)} )</td>
<td>Akgun and Doymaz (2005)</td>
</tr>
<tr>
<td>Verma et. al.</td>
<td>( R = a e^{x p (-b t)} + (1 - a) e^{x p (-c t)} )</td>
<td>Akpinar et al., (2006)</td>
</tr>
<tr>
<td>Midilli et. al.</td>
<td>( MR = a e^{x p (-b t d)} + c t )</td>
<td>Sacilik et al., (2006)</td>
</tr>
</tbody>
</table>

\( a, b, c \) and \( d \) are constants and coefficients in the drying models.
RESULTS AND DISCUSSION

The effect of microwave output power on the moisture content, moisture ratio, drying rate and drying time of scent leaf was investigated at 90, 180, 360, 540, 720 and 900 W microwave output powers. The effect is summarized in the plot of moisture ratio versus drying time of scent leaf samples at various microwave power settings in Figure 1. The effect showed that the moisture ratio decreased with significant increase in the drying time. The drying process followed a falling rate pattern with rapid decrease in the moisture ratio at the higher microwave powers. The change in the moisture ratio became more rapid at higher microwave powers and steady at lower microwave powers.

As stated above, the experimental results during the microwave drying of scent leaves demonstrated that drying took place only in the falling period thus followed a falling rate pattern (i.e. constant rate period was not observed); this was controlled by the internal liquid diffusion of the samples all through the entire process. It was obvious that the drying time was governed by the internal opposition to mass transfer as it occurred through falling rate period (Demirhan and Özbek, 2010). A gradual change in the shape of the curves was also observed, there was a shift from inverted sigmoid shape at lower power settings to upward concave shape as the microwave output powers increased. This is compared to the trend by Miano and Augusto (2015) reported shifts in sigmoidal shapes to downward concave curves in the hydration study of adzuki beans with respect to initial moisture content.

The determined critical moisture content was found to be equal to the initial moisture content (86.61 g water/g dry matter). The entire process was controlled by internal mass transfer resistance (Gogus and Maskan, 1999). These results agreed with Maskan (2000), Panchariya et al. (2002), Wang et al. (2007), Dadali et al. (2007c) and Demirhan and Özbek (2010) results for banana, black tea, apple pomace, spinach and basil leaves respectively.

The times required to dry scent leaf samples from initial moisture content of 86.61± 1.25 (g water/g wet matter) to the final moisture content of 4.47 ± 0.98 (g water/g wet matter) were 22, 14, 6, 5, 4.5 and 10 minutes at 90, 180, 360, 540, 720 and 900 W respectively. The drying microwave power produced a significant effect on the drying time. This was because of the microwave volumetric heating characteristics where the samples created a significantly high vapour pressure difference between its centre and surface, thereby making the mass transfer of samples more rapidly at higher microwave power heating as more heat was generated.

The drying time of the samples decreased as the microwave output power increased, and the microwave-drying processes took 4.5 minutes to 22 minutes to dry the samples. The drying time was reduced by 79.56 % at 720 W. The possible reason why at 900 W the dehydration rate was slower than 720 W might be related the cell integrity and the mass transfer phenomenon in the sample (Oliveira et al., 2013). The expectation is that as the power increases, diffusion rate increases with resulting lower water holding capacity. But at the high power, evaporation takes place very fast, and the porosity of the cells close to the surface decreases drastically, thereby entrapping more moisture at the core of the sample, which took more energy and time to migrate to the surface. The significant reduction in the drying times with microwave output power increase was comparable with Demirhan and Özbek (2010) for basil leaf respectively. However, the values were extremely low compared to the results obtained in Akpinar (2006) and Mepba et al. (2007) on solar drying of basil leaves and sun drying of some Nigerian leafy vegetables respectively, which spanned between 5 h and 2 days. The results obtained showed that microwave drying
Figure 1: Moisture ratio against time at different microwave power outputs

Figure 2: DR versus drying time of scent leaves samples at different drying microwave power

compared to solar drying and the sun drying shortened the drying time significantly being more efficient.

The drying rate (DR) was expressed as the amount of the evaporated moisture ratio over time. Figure 2 presented the drying microwave powers variation effect on the DR versus drying time profile of scent leaf samples. The DR was observed for all the microwave powers. In Figure 2, the drying rate thresholds decreased with increasing drying time across microwave power drying conditions, but decreased with moisture content. The drying process followed a falling rate pattern. It increased as the microwave power increased except for microwave power, 900 W, thereby reducing the total drying time with microwave power increase. The DR decreased with time with decreasing moisture content. This shows that at very high microwave power, there is high resistance to moisture transfer from the
core to the surface of material due to highly reduced porosity and damaged cells which thus trapped moisture beneath the damaged cells. As the microwave power levels increased, the drying rates also increased with threshold DR values 0.0393, 0.1112, 0.1453, 0.2046, 0.2938, and 0.4263 g water/g dry matter.min, at the applied microwave powers of 90, 180, 360, 540, 720 and 900 W respectively. The initial phase of the drying revealed that the high DR and high absorption of microwave power were consequent upon high moisture diffusion, which leave high drying effect. Moisture loss with respect to time presented a decrease in microwave power absorption during the process, which consequently led to a fall in the DR.

Figure 3 shows the drying rate curves of scent leaf at various microwave powers. From Figure 3, the drying rates increased as microwave power increased, implying that at higher power, heat and mass transfer are high, therefore there was excessive water loss. At the beginning of the drying process, the drying rates were high (rapid evaporation) until the thresholds were reached and the rates gradually decreased with moisture ratio. This is because of reduced porosity and increased shrinkage in the samples which account for increased resistance to water movement that consequently resulted in further fall in the drying rates (Doymaz et al., 2015).

Effective moisture diffusivity
To understand the mass transfer mechanism of scent leaves at different microwave output powers, the effective moisture diffusivity was calculated. The effective moisture diffusivity was calculated using the slopes of the plots of the logarithm of moisture ratio values, ln(MR) against drying time (t) of the experimental data at different microwave output powers. The linearity of the relationship between ln(MR) and drying time (t) is illustrated in Figure 4 for various microwave output. The experimental drying data dependence though is not strictly linear on a logarithmic scale. The effective moisture diffusivity values ($D_{eff}$), the corresponding values of coefficients of determination ($R^2$) and the standard error (SSE) of Eq. (5) are presented in Table 2 for various microwave output.

Consequently, the slope was regarded as a first useful approximation to the value of the diffusivity. The values of $D_{eff}$ increased with increasing microwave power as shown in Figure 5. This was because the increased heating energy increased the water molecules activity and resultant higher moisture diffusivity. The microwave dried effective moisture diffusivity of scent leaves varied from $2.73 \times 10^{-10}$ to $1.82 \times 10^{-8}$ m$^2$/s, which agrees with the result obtained by Demirhan and Özbebek, 2010 who obtained $7.899 \times 10^{-10}$ to $2.168 \times 10^{-8}$ m$^2$/s microwave dried basil leaves. The values though were higher than the values of $6.44 \times 10^{-12}$ m$^2$/s obtained by Akpinar (2006) for sun dried basil leaves. Similarly, it agreed with the findings of Bakal et al. (2011), Lin et al. (2005), Aghbashlo et al. (2011), McMinn et al. (2003) and Khraisheh et al. (1997) who obtained $5.612 \times 10^{-9}$ to $1.317 \times 10^{-8}$ m$^2$/s, $4.606 \times 10^{-4}$ to $7.065 \times 10^{-4}$ m$^2$/s, $3.17 \times 10^{-7}$ to $15.45 \times 10^{-7}$ m$^2$/s and $2.90 \times 10^{-4}$ to $4.88 \times 10^{-4}$ m$^2$/s, $7.04 \times 10^{-4}$ to $24.22 \times 10^{-4}$ m$^2$/s, and $3.15 \times 10^{-8}$ to $5.36 \times 10^{-8}$ m$^2$/s for fluidized bed dried potatoes, far-infrared freeze-dried sweet potato cubes, continuous band thin-layer dried carrot cubes and convective, microwave and combined dried potato cylinders, respectively. The general range values of $D_{eff}$ for food materials is from $10^{-9}$ to $10^{-11}$ m$^2$/s. The microwave power effect on the effective moisture diffusivity of scent leaf is defined by equation (14)

$$D_{eff} = 3 \times 10^{-12}(P) + 2 \times 10^{-10}$$

This result agrees with Doymaz et al. (2015) findings on microwave drying of green bean slices.
Figure 3: Drying rate curves of scent leaf at various microwave powers

Figure 4: Microwave power effect on samples drying dependence on MR logarithmic scale

Figure 5: The effective diffusivity values for microwave drying of scent leaf
Modelling of Drying Curve
The effect of microwave output power on drying kinetics of scent leaves was described using seven thin-layer drying models. The Midilli et al. model was observed to be the most appropriate for the description of the experimental drying process data with the higher values the coefficient of determination, $R^2$ and reduced normalized root mean square error (NRMSE), sum of square of residuals (SSE) and root mean square error (RMSE) for all drying microwave powers compared with the statistical values obtained for other models. The estimated parameters and statistical analysis of this model for a given drying condition are presented in Table 3.

The Midilli et al. model statistical values for $R^2$, RMSE, SSE and NRMSE in the drying process are $0.9905 < R^2 < 1$, $0 < $RMSE$ < 3.03 \times 10^{-2}$, $0 < $SSE$ < 0.74 \times 10^{-2}$, and $0 < $NRMSE$ < 3.40 \times 10^{-2}$ respectively. As shown in Figure 6, there was a good agreement between the predicted and observed moisture ratio data with the coefficient of correlation, $R^2 = 0.9981$.

Activation Energy
In standard microwave oven drying process, the temperature is not a measurable variable. Therefore, to calculate the activation energy, Arrhenius equation was modified and used to illustrate the relationship between the kinetic rate constant and the ratio of the microwave output power to sample amount in place of temperature.

To evaluate the effective moisture diffusivity and the drying rate constant for of scent leaves at any microwave output power and sample amount, the Arrhenius - type dependent equation was used as derived by Dadali et al. (2007a,b). The calculated activation energy of scent leaves was $31.801 \text{ W/g}$. The estimated activation energy, $E_a$ was obtained from the plot of natural logarithm of $D_{eff}$ against sample amount (mass), $m (g)$ power, $P (W)$.

A straight-line relationship between the two variables was observed in the studied microwave power range, which indicated Arrhenius - type dependence. The (-$E_a$) equals to the slope of the line and $\ln (D_o)$ equals to the intercept as represented in equation (15).

$$D_{eff} = D_o e^{-\frac{-E_a}{mP}} \quad (15)$$

Equation 15 presents the samples’ weight effect on the $D_{eff}$ of samples with the following coefficients:

$$D_{eff} = 2.63 \times 10^{-9} \exp \left(\frac{31.801 m}{P} \right) \quad (R^2 = 0.969) \quad (16)$$

From the modified Arrhenius type exponential equation (14), the estimated values of $D_o$ and $E_a$ are $1.0577 \times 10^{-9} \text{ m}^2/\text{s}$ and $31.801 \text{ W/g}$, respectively.
Table 3: Curve fitting criteria for the thin-layer models of Scent leaves

<table>
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<th>Thin-layer model</th>
<th>Statistical parameter</th>
<th>Model constants</th>
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CONCLUSION

The varied microwave output powers effect on the drying characteristics of the scent leaves was investigated in a microwave oven. Compared to the traditional sun drying and the conventional hot-air drying methods, microwave drying of scent leaves successfully decreased significantly the drying time of the process by 79.56 %. The process of microwave drying of the samples occurred in the falling-rate period. The Midilli et al. model among several other mathematical models employed provided the best
description of the process, showed good consistency and agreement between the obtained experimental and predicted moisture ratio data over the microwave power range with result values of 0.9930 < $R^2$ < 1, 0.000 × 10^{-2} < RMSE < 4.80 × 10^{-2}, 0.000 × 10^{-2} < SSE < 1.03 × 10^{-2} and 0.000 × 10^{-2} < NRMSE < 2.57 × 10^{-2}. The effective moisture diffusivity value of scent leaf samples varied between 2.30138 × 10^{-8} and 9.69307 × 10^{-8} m^2/s for the microwave power range.

An approximate linear relationship between the data of ln(MR) and drying time (t) was obtained to get the effective moisture diffusivities, whose values ranged and increased from 2.73 × 10^{-10} to 1.82 × 10^{-9} m^2/s. The calculated pre-exponential factor, $D_0$ and activation energy, $E_a$ values of scent leaves obtained using Arrhenius-type dependent equation were 1.0577 × 10^{-9} m^2/s and 31.801 W/g, respectively.

REFERENCES


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