Vacuum-microwave drying characteristics of spearmint leaves

Debabandya Mohapatra\textsuperscript{a,b}\ast, Saroj Kumar Giri\textsuperscript{a,b}, Suresh Prasad\textsuperscript{a,c}, Abhijit Kar\textsuperscript{d} and Prabhat K. Nema\textsuperscript{a,e}

\textsuperscript{a}Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, 721302, India.
\textsuperscript{b}Current address: Agro produce processing Division, Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India.
\textsuperscript{c}Department of Chemical and Biochemical Engineering, Indian Institute of Technology, Patna, India.
\textsuperscript{d}Post harvest technology Division, Indian Agricultural Research Institute, New Delhi.
\textsuperscript{e}NIFTEM, Kundli, Sonepat, Haryana, India.

\ast Corresponding Author:
Debabandya Mohapatra
E-mail: debabandya@gmail.com

Received: 07/06/2014
Revised: 24/06/2014
Accepted: 25/06/2014

Abstract
Mint is one of the favoured aromatic herbs used in the culinary practice of different regions in the world. Vacuum-microwave drying characteristics of Indian spear mint leaves were carried out at 70 mm Hg vacuum and at three different power levels (150, 350, 500W). Drying data was fitted to different drying models and Weibull model was found to be best suited to describe the drying process. Suitability of the models was chosen on the basis of the minimum chi-square, root mean square error and regression coefficient higher than 0.99. It was observed that as the microwave power level increased from 150 W to 500 W, drying time reduced from 85 to 40 minutes, as at higher power density the volumetric heat generation would be more. This resulted in higher water evaporation rate at high power level, which ultimately reflected in total drying time. The drying efficiency decreased as the drying time increased and increased as the power level increased. Chlorophyll content decreased as microwave power level was increased.

Keywords: Spearmint leaves, vacuum-microwave drying, Weibull model, drying efficiency, chlorophyll content.

Introduction
Several drying methods have been employed to dry biological materials. Of late, use of microwave energy for drying of biological materials has gained a foothold in drying industries due to its relative advantages over conventional drying. This process requires relatively small drying time hence, product quality is maintained. This method can enable to have bone dried product as the heating involves polarization of molecules and atoms, which when oscillate at high frequency to align them under the influence of alternating electromagnetic fields, dissipate heat energy (Vega-Mercado \textit{et al.}, 2001).

Vacuum drying is an alternative to conventional hot air drying as it allows water to vaporize at a lower temperature than at atmospheric conditions. Therefore, products can be dried without being exposed to high temperature. Moreover, the absence of air during dehydration diminishes oxidation reactions. Because of these advantages the colour, flavour and texture of dried products are improved. But, in vacuum drying heat transfer to the solid phase is slowed down significantly, due to the absence of convection which may be enhanced by microwave radiation. Thus, vacuum-microwave drying may act as a complementary method to the conventional ones for drying of mint which is rich in heat sensitive volatile compounds.

Many drying models have been used to predict the vacuum-microwave drying (VMD) behavior of different fruits (Kiranoudis \textit{et al.}, 1997), mushroom (Giri and Prasad, 2007; Giri \textit{et al.}, 2014), mint (Therdthai and Zhou, 2009), but limited information is available on the VMD behaviour of spearmint (\textit{Mentha spicata}), which is one of the widely grown mint variety in Indian sub-continent. But, it is highly perishable and requires proper drying method to preserve its characteristics aroma and taste as well as nutrient. Though hot air, solar, convective-microwave, vacuum microwave drying methods have been employed for drying of mint, the quality is compromised due to degradation of chlorophyll content and other volatile matters (Doymaz, 2006; Therdthai and Zhou, 2009; Sledz and Witrowa-Rajchert, 2012; Mohapatra and...
Prasad, 2013). In this study attempt was made to find out the VMD characteristics of spearmint leaves and the energy consumption in the process. The data will be useful in designing dryer and drying conditions for obtaining dehydrated mint leaves.

Materials and Methods

Fresh spearmints (Mentha spicata) were procured from the local market of Kharagpur, West Bengal. The branches were thoroughly washed to remove the dirt adhering to the leaves. Only green and healthy leaves were picked for experimentation and the extra moisture was blotted out by tissue paper. Some samples were kept in oven to find out the initial moisture content using hot air oven method of AOAC. The leaves were used for drying in VMD set up. For each experiment about 50g of sample was used. Experiments were carried out in triplicate and average value was taken for calculation.

Vacuum- Microwave Drying

The drying set up consists of (i) microwave oven (IFB, model electron, 600W, 2.45GHz) (ii) 230V AC variac (iii) vacuum pump (0.25hp) with vacuum gauge, pressure regulating valve and water condensing unit (iv) a glass container for the materials to be dried placed inside the microwave cavity and (v) an electronic balance (Mettler, USA), on which the rotating table was placed, so that the weight of the materials can be taken without removing the sample holder from the microwave cavity (Giri et al., 2014). About 50g of spearmint leaves were taken for each drying experiments in the microwave vacuum dryer at different microwave power and a constant vacuum level of 70mm Hg. The sample remained in the container for a specified time interval while drying took place. The weight of the sample was recorded at every 5 min intervals. The samples were dried till the moisture content was reduced to bone dry. The experiments were conducted at 3 power levels (150, 350 and 500W) at 70mm Hg pressure.

Modeling drying data

Since, microwave drying takes place through volumetric heating of the product wherein the moisture is evaporated due to polarization and collision in the alternating magnetic field, Fick’s law of diffusion does not hold good in this case. Therefore, a conjugate approach was followed for describing the vacuum-microwave drying of mint leaves. Researchers have applied Henderson and Pabis, exponential, page’s, Lewis’s, Wang and Singh, two-term, sigmoidal models etc for explaining the drying behaviour of various agricultural products (Mohapatra and Rao, 2005; Giri and Prasad, 2007; Nema et al., 2013; Giri et al., 2014).

In this case, Weibull model was used to characterize the VMD of spearmint leaves. Weibull model has been used to describe the microbial growth and death kinetics (Cunha et al., 1998; Lebovka and Vorobiev, 2004; van Boekel, 2008), enzyme kinetics (Mohapatra et al., 2008), colour and hardness evolution of mushrooms (Mohapatra et al., 2010), thin layer convective drying and osmotic dehydration (Bhaskaracharya et al., 2009; Uribe et al., 2009). Weibull probabilistic model has been used in cases where, the system or events have some degree of variability. The function can be represented as follows:

$$ F(t) = 1 - e^{-\left(\frac{t}{a}\right)^{\beta}} $$

Where, $\alpha$ is the scale factor or rate of reaction and $\beta$ is the shape factor or behaviour index. The probability function has uniqueness, where it can be reduced to zero order when $\beta = 1$ and failure rate will be increasing with time when $\beta > 1$ or decreasing when $\beta < 1$ (Cunha et al., 1998). This model allowed for a more realistic interpretation of the data in the case of multiple sources of variation.

Microwave heating and moisture transfer has been suitably described by various researchers. The value of drying constants has been reported in many cases for the bio-products dried at various microwave power levels and vacuum conditions. In the present investigation of various drying models were tested along with Weibull distribution model, with the experimental value for the VMD of spearmint leaves.

$$ MR = M/M_0 = F(t) $$

Where, MR= moisture ratio, Mo and M are the moisture content at drying time $t=0$ and $t=t$, respectively. For the calculation purpose MR was taken as M/Mo, as the equilibrium moisture content during microwave vacuum drying is considered zero, due to vacuum conditions of the process (Giri and Prasad, 2007). Model co-efficients were evaluated through non-linear regression analysis using the statistical analysis tool SPSS 6 (SPSS, USA). The goodness of fit of the tested mathematical models to the experimental data was evaluated from the coefficient of determination ($R^2$), root mean square error (RMSE) and reduced chi-square ($\chi^2$). These parameters can be calculated as follows:

$$ RMSE = \left[ \frac{1}{N} \sum_{i=0}^{N} \left( MR_{pre,i} - MR_{obs,i} \right)^2 \right]^{\frac{1}{2}} $$
The energy efficiency of the MVD of spearmint leaves was evaluated in terms of drying efficiency (DE). The drying efficiency depends on the process variables and is calculated as the ratio of water evaporated for the sample to the energy supplied to the system (Giri et al., 2014).

\[ DE = \frac{M_w \lambda_w \Delta t}{Q} \times 100 \]

Where, DE is drying efficiency, \(\%\), \(M_w\) is the mass of water evaporated (g) during drying time \(\Delta t\) (s), \(\lambda_w\) is the latent heat of vaporization (J/g) at the corresponding pressure, \(Q\) is the sum of microwave power (W) and power consumed by the vacuum pump.

Chlorophyll content determination
Chlorophyll a, b and total chlorophyll content of the fresh as well as dehydrated samples were determined by spectrophotometric method (Rangana, 1986). The samples were extracted with 85% acetone, which was then transferred to ether and OD was taken at 663 and 645 nm for calculation of chlorophyll content with ether as blank.

Results and Discussion
Drying rate
The relationship between drying rate and average moisture content for different power levels is presented in Fig.1. The drying behaviour of the VMD of mint leaves initially showed a constant drying rate as volumetric heating was governing the phenomenon. Moreover, the moisture evaporated due to microwave heating was removed in the suction, so that there is no surface deposition of evaporated moisture. Vacuum also lowers the boiling point of the liquid thus, making the moisture evaporate at lower temperatures. As drying proceeded drying rate was found to diminish. Thus, corroborating the fact that at the last stage of drying, diffusion is the governing process as moisture content decreases and the product temperature increases. As microwave heating is governed by the presence of polar molecules like water, the volumetric heat generation in the drying product would diminish with decrease in moisture level, despite being exposed to same power level (Giri et al., 2014). This accompanied in generation of hot spots in the product and eventual burning of some product as temperature shoots up.

It was also observed that as the power level increased from 150 to 500W, the drying rate was higher. This was due to the fact that higher power level would necessitate higher power density, product weight being same for the experiments, volumetric heat generation was higher, which compelled the moisture to evaporate out of the product at a faster rate. Similar, observation was reported by Ozbek and Dadali (2007) for microwave drying of mint leaves. The total drying time was 85, 50 and 35 minutes, for the power levels of 150, 250 and 500W, respectively.

Drying model
Weibull model was used to describe the drying behaviour of VMD of spearmint leaves. It was compared with some of the widely used for such as Henderson and Pabis, Lewis and logarithmic model (Table 1). Weibull model outperformed other drying models having highest \(R^2\) (0.9974) and minimum average chi-square value (0.0033) and RMSE (0.06779) values (Table 1).

It was found that as the power level increased the reaction factor \(\alpha\), which is analogous to drying constant decreased and \(\beta\), the shape factor increased.
Table 1: Empirical constants and statistical results of microwave-vacuum drying of spearmint leaves obtained from various drying models for different MW power level

<table>
<thead>
<tr>
<th>Model</th>
<th>MW power level, W</th>
<th>Constants</th>
<th>$R^2$</th>
<th>$\chi^2$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henderson</td>
<td>150</td>
<td>a=1.0850, k=0.0463</td>
<td>0.9714</td>
<td>0.003644</td>
<td>0.2908</td>
</tr>
<tr>
<td>and Pabis</td>
<td>350</td>
<td>a=1.0529, k=0.0952</td>
<td>0.9774</td>
<td>0.00421</td>
<td>0.2443</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>a=1.0359, k=0.1334</td>
<td>0.9787</td>
<td>0.003454</td>
<td>0.1867</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.9758</td>
<td>0.00377</td>
<td>0.2406</td>
</tr>
<tr>
<td>Lewis</td>
<td>150</td>
<td>k=0.0432</td>
<td>0.9643</td>
<td>0.00417</td>
<td>0.3313</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>k=0.0913</td>
<td>0.9743</td>
<td>0.00418</td>
<td>0.2675</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>k=0.1299</td>
<td>0.9773</td>
<td>0.00316</td>
<td>0.1977</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.9720</td>
<td>0.00384</td>
<td>0.2655</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>150</td>
<td>a=1.1687, b=-0.1179, k=0.0353</td>
<td>0.9865</td>
<td>0.00132</td>
<td>0.2189</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>a=1.0939, b=-0.0523, k=0.0835</td>
<td>0.9826</td>
<td>0.00288</td>
<td>0.2449</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>a=1.0747, b=-0.0456, k=0.1188</td>
<td>0.9833</td>
<td>0.00324</td>
<td>0.2731</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.9841</td>
<td>0.00227</td>
<td>0.2456</td>
</tr>
<tr>
<td>Weibull</td>
<td>150</td>
<td>$\alpha$= 24.7595, $\beta$=1.4715</td>
<td>0.9954</td>
<td>0.00056</td>
<td>0.0740</td>
</tr>
<tr>
<td></td>
<td>350</td>
<td>$\alpha$= 11.6450, $\beta$= 1.4991</td>
<td>0.9977</td>
<td>0.00036</td>
<td>0.0488</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$\alpha$= 8.2783, $\beta$= 1.5723</td>
<td>0.9990</td>
<td>0.00016</td>
<td>0.0616</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.9974</td>
<td>0.00033</td>
<td>0.0615</td>
</tr>
</tbody>
</table>

Similar kinds of findings are also reported by Nema et al. (2013) for pulse microwave drying of ginger, fitted to page’s model, which is a modified Weibull model. The predicted and observed value of moisture ratio for all power levels is shown in Fig 2. The linear trend having 45° with the axis confirms the suitability of the model fitting to the observed data, for the experimental range taken up in this investigation.

Fig 3 depicts the observed and predicted values of moisture content by Weibull model with respect to drying time for all power levels. A good agreement was found between the experimental and predicted values with the $R^2$-values of greater than 0.99.

Fig 4: The variation in drying efficiency with moisture content and microwave power level for VMD of spearmint leaves

Chlorophyll content of the spearmint leaves

The average initial moisture content of the fresh spearmint leaves were 87.28 % (wb). The chlorophyll a, b and total of fresh spearmint leaves were 12.54, 9.70 and 9.77mg/g dry weight basis, respectively. The
chlorophyll a, b and total of VMD spearmint leaves at 150W decreased to 11.5, 8.57 and 8.67mg/g dry weight basis, respectively. Whereas, the chlorophyll a, b and total decreased to 11.25, 8.35 and 8.45mg/g dry matter for the sample dried at 350W. As the microwave power increased to 500W, the chlorophyll a, b and total further decreased to 10.94, 7.64 and 7.71mg/g dry matter. The results are in line with the findings of Śledź and Witrowa-Rajchert (2012), who have observed the decrease in chlorophyll content and colour due to microwave air drying. The total chlorophyll contents of the VMD spearmint leaves were higher as compared to hot air dried samples reported from the previous work of Mohapatra and Prasad (2013). The total chlorophyll content of the spearmint samples dried at 30, 45 and 60°C were 5.15, 5.05 and 4.55mg/g db, respectively. Since, microwave heating and evaporation of moisture occurs due to dipole moment of water molecule, this phenomenon is suitable for high moisture product, as moisture removal occurs without adversely affecting the surface colour and degradation of colour pigments (Alibas, 2007). However, at higher power level as the moisture content in the product diminished product burning takes place which adversely affects the colour and other qualities of the product.

Conclusions

The total drying time decreased from 85 to 35 min as the microwave power level increased from 150 to 500W at constant vacuum. The drying was faster at higher power levels, so is the drying efficiency (43%). However, there is higher chlorophyll degradation at higher power level. Weibull model was found to be a good fit to describe the vacuum microwave drying of spearmint leaves with minimum chi-square and RMSE value as compared to other widely used models. Vacuum microwave drying may be employed for spearmint leaves to obtain a superior quality dried products with higher chlorophyll content.

References

Mohapatra et al...Vacuum-microwave drying characteristics of spearmint leaves
