Analyses and Modelling of Moisture Desorption at Different Methods of Mint (Mentha spicata Huds) Leaves Drying

B. Hosseinzadeh, M.H. Khoshtaghaza*, A. Mahdavian and G.H. Najafi

Department of Mechanics of Agricultural Machinery, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-111, Tehran 14114, Iran

*Corresponding author. Email: Khoshtag@modares.ac.ir

Abstract

In the current study the thin-layer drying characteristics of mint leaves in four methods of traditional drying, solar drying, hot air drying and microwave drying were investigated. In each method of drying, mint leaves with two sizes of 1 and 5 cm were dried and the results were analyzed. The research was also conducted to a vision-smell test panel for assessment the quality of the samples dried at the four drying methods. The qualitative assessment was performed regarding to the dried samples color, smell, and marketing tendency. The 1 cm mint slices showed higher evaporation rate than that of 5 cm slices, so that the amount of moisture desorption at the first hour of drying process in the case of 1 cm mint slices was 6%, 7% and 6% higher than that of 5 cm slices, respectively, in traditional, solar and hot air drying methods. The results indicated that there was an acceptable marketing tendency for microwave and solar dried mint samples as compared with the two other drying methods. The drying data from the four evaluated drying methods were finally fitted to seven different mathematical models which had been previously developed by other researchers. The results showed that “Varma et al” model, “Two Term” model and “Midili et al” model were the best models to explain thin-layer drying behavior of mint leaves for traditional drying, hot air drying and solar drying methods, respectively. “Two Term” model was also found to be the best model expressing the thin-layer drying behavior of mint leaves in traditional drying.

Keywords: mint, drying, modeling, traditional, solar, microwave

Introduction

Mint (Mentha spicata Huds) is a genus of the Labiatae family, which comprises a wide number of species, varieties and hybrids. It has been used as a medical and aromatic plant since ancient times. Its leaves are used for flavoring, tea infusions and spicing. In addition, mint oil is used to treat several diseases. Mint leaves are refreshing, antiseptic, anti-asthmatic, diaphoretic, stomachic, and antispasmodic. It helps in colds, flu, fever, poor digestion, motion sickness, food poisoning, rheumatism, hiccups, stings, ear aches, flatulence and for throat and sinus ailments. It is rich in calcium and phosphorus. Because of high water content (78–82%, w/w), mint is ordinarily dried for marketing to inhibit microorganism growth and prevent degradation as a result of biochemical reactions. Also, drying brings about substantial reduction in weight and volume, minimizing packaging, storage and transportation costs (Kavak Akpinar, 2010). Due to its high moisture content, in order to preserve this seasonal plant and make it available to consumers during the whole year, it should be undergone specific technological treatments, such as some drying process.

Different methods are used for drying agricultural foods. Proper selection and application of drying is very important to save the product quality. During drying process of agricultural
products, water and heat are transferred simultaneously. Selection the drying method is dependent on the different properties of products. In many rural parts of developing countries, utilization of industrial dryers is not affordable for the farmers and subsequently, these types of dryers are rarely used. Traditional drying, under direct radiation of sun is accompanied with some disadvantages and limitations such as excessive losses due to insects and birds attack, unexpected rainfall and fungus pollution. Use of high temperature drying, although it may result in an increase in the products moisture desorption, but in many cases of foodstuffs, it damages the texture of the product. By controlling the drying conditions, the desirable outcomes of drying could be reduced (Lotfalian et al., 2010a; Lotfalian et al., 2010b).

One of the most important aspects of drying technology is the mathematical modeling of the drying processes and equipment. Its purpose is to allow design engineers to choose the most suitable operating conditions and then size the drying equipment and drying cabinet accordingly to meet desired operating conditions. The principle of modeling is based on having a set of mathematical equations that can adequately characterize the system. In particular, the solution of these equations must allow prediction of the process parameters as a function of time at any point in the dryer based only on the initial conditions (Gunhan et al., 2005).

Recently, many studies have been conducted on drying characteristic of mint leaves using different techniques. Lebert et al. (1992) examined the effect of drying conditions on drying kinetics of mint. They studied several parameters including humidity, drying air temperature and velocity, whether or not the leaves were blanched before treatment, as well as temperature changes during drying. The results obtained in their study verified, with good reproducibility, that temperature is the main factor in controlling the rate of drying, and that when blanching is limited to 15 s, drying times were divided by 5. Hossain and Bala (2007) used a tunnel solar dryer for drying of spices. This dryer received air from one side of the tunnel from a blower and blew it throughout the tunnel. In this dryer air flow and sunlight caused an increase in evaporation rate and consequently increased drying speed. Ozbek and Dadali (2007) investigated the effect of microwave drying technique on moisture content, moisture ratio, drying rate, drying time and effective moisture diffusivity of mint leaves. Colak et al. (2008) performed the energy analysis of a single layer drying process of mint leaves in a ground source heat pump tray dryer. Muller et al. (1989) used a greenhouse-type solar dryer for mint drying. Akpinar (2006) examined the sun drying behavior of mint. Doymaz (2006) determined the thin-layer drying behavior of mint leaves for a temperature range of 35-60 °C in a cabinet dryer. Janjai et al. (2008) evaluated the performance of a roof-integrated solar dryer for herbs and spices and compared its results with traditional drying method. Results showed the higher quality of dried spices with this method in comparison with traditional method. Also obtaining higher added-value and rapid capital return has been proved in solar drying method. Therdthai and Zhou (2009) determined the characteristics of microwave assisted vacuum drying of mint leaves in comparison with conventional hot air drying and their effects on the color and structure of the dried leaves. They reported that the effective moisture diffusivity was significantly increased when microwave drying was applied under vacuum condition, compared with hot air drying. Base on color, the microwave vacuum dried mint leaves were light green/yellow whereas the hot air dried mint leaves were dark brown.

In the literature, although there were several works performed on mint drying using different methods, no comprehensive research was found on comparing all of the common different methods of mint leaves drying accompanied with the analyses and modeling of moisture desorption rate during each method of drying. Hence, the objective of this study was to analyze and model of moisture desorption at different methods of mint leaves drying and to determine the dried leaves quality at each method of drying. The results of this study could be used to optimize the mint leaves drying processes and also help to preserve the product quality for longer times.
Materials and Methods

Location of the Study and Sample Preparation

The research was conducted in the Laboratory of Biotechnology and Food Engineering, Faculty of Agriculture, University of Shahrekord, Iran. Shahrekord city is the capital of the Chaharmahal and Bakhtiari Province. It is located at the longitude of 50°49’ and latitude of 32° 20’ and above 2078 m of sea level in the western part of Iran. In the area of study, mint leaves are widely used for flavoring, tea infusions and spicing consumptions.

The mint leaves used in this study were purchased from a local market in Shahrekord city. Before starting the experiments, the samples were initially cleaned to remove all foreign materials such as dust, dirt, grit and damaged leaves by pests.

Experimental Set Up

In the current study, mint leaves drying trend were investigated at four different thin layer drying methods, namely, traditional method (spreading the leaves on the ground while subjecting open sun light), solar drying (indirect and passive type), hot air drying, and microwave drying methods. The layer thickness at all of the methods was 1 cm.

For conducting the experiments, the sample mint leaves were initially removed from their stalks. The leaf samples were then sectioned into two sizes of 1 and 5 cm. Afterwards, the mint leaves were taken under the laboratory conditions till their moisture content became identical. In order to determine the initial moisture content of meant leaves, 50 g of samples were dried in an oven at 105 ºC for 24 h (Ozbek and Dadali, 2007). The samples were weighed by a digital weigh scale with an accuracy of 0.1 g (AND Model 6000i, Japan) and poured into numbered trays. In each drying method, 950 g of samples were taken into the dryers. The solar dryer and the samples which should be dried at traditional method were both placed at an enclosure subjected to sunshine and the hot air dryer were placed beside them for providing a similar environmental condition. The drying temperature at traditional and solar drying methods was equal to 21.3 ºC and 32.7 ºC, respectively. The drying temperature and airflow rate at hot air drying method were selected as 65 ºC and 1 m s\(^{-1}\) (Ozbek and Dadali, 2007). The microwave dryer which used (International Model, Japan) was operating at 900 W having airflow rate of 0.1 m s\(^{-1}\). Because of a short time used for drying the samples in the microwave type dryer, the drying trend was evaluated every 15 seconds.

The weather conditions such as air temperature, barometric pressure, relative humidity (RH) and the wind speed were measured in the experiments. The mean values of air temperature, barometric pressure, relative humidity (RH) and the wind speed during the experiments were respectively equal to 21.3 ºC, 1020 kPa, 38% and 7.6 m h\(^{-1}\). The experiments were started at 8.00 AM (23\(^{th}\) September, 2010) and continued until the time in which the moisture desorption rate from the leaves approached to a constant value. During each test, the mint leaves were weighed in time intervals of 1 h and the weight of the samples at each time was recorded in a PC for further analyses. The quality of the dried leaves at each experiment was also examined by the vision-smell test panels. In order to evaluate the quality of the dried samples, the leaves which had been dried at each methods of drying were shown to 100 persons and the tendency to choose the samples by the users were investigated. The qualitative assessment of the dried leaves were made in terms of the product's colour and scent after drying process and also tendency to buy the dried samples by customers.

The change of moisture in mint leaves during drying was expressed as moisture ratio (MR) defined as (Therdthai and Zhou, 2009):

\[
MR = \frac{X_i - X_e}{X_o - X_e} \times 100
\]

Where, \(X_i\) is moisture content (% d.b.) at time i, \(X_e\) is equilibrium moisture content (% d.b.), and \(X_o\) is initial moisture content (% d.b.).

The values of moisture ratios obtained in this study and at different drying methods were compared to the models had been previously developed by the researchers in the case of agricultural materials. In order to determine the best fitting model, two indexes namely, coefficient of determination (\(R^2\)) and root mean square of error (RMSE) were used.
Qualitative Assessment of the Product

In order to determine the quality of the samples dried with four drying methods of traditional, solar, hot air and microwave, a qualitative test was made. Samples of mint leaves dried at each drying methods were chosen and the quality of them was assessed by 100 observers. The evaluated qualitative characteristics were color, scent, and tendency to buy.

Experimental Design and Statistical Analysis

The research carried out was based on a factorial experiment on the basis of completely randomized design. During each test, the sampling from the leaves at each time interval was replicated three times and the average values were reported. The effects of leaf slices size and drying time on the leaves qualitative characteristics and moisture desorption were evaluated using analysis of variance (ANOVA), and mean significant differences were compared using the least significant difference (LSD) test at 1% significant level using SAS 9.1 software.

Results and Discussion

Traditional Drying Method

The results of ANOVA indicated that the main effects of samples slices and drying time and also their interaction effect on the moisture desorption were significant (P<0.01). The moisture evaporation from the mint leaves was initially started at high rates because of the higher moisture existing on the leaves surface at the first times of drying process. The moisture desorption from the samples reached to a constant rate at the end times of drying. Figures 1 and 2 show comparison of means of evaporated water and moisture ratio regarding to drying time in traditional method. The total time of drying, considering the season in which the experiments were conducted (September 2011) and the weather conditions, was 17 hours. According to Figure 1, by increasing the drying time the mass of evaporated water increased. With decreasing the samples slices, the contact area and also the crushed section by the knife increase and cause the moisture desorption rate to increase. The moisture desorption rate for the 1 cm meant slices were 2.8% more than that of 5 cm slices.

As shown in Figure 1, at the first hour of drying, more than 27% of samples moisture was desorbed and at less than three hours more than 50% of evaporable moisture was desorbed. The main reason of a decrease in the rate of moisture desorption from the mint leaves at the end times of traditional drying method is variability of sun ray during the drying process. This is considered as one of the major disadvantages of traditional drying method.

Solar Drying Method

The results of the ANOVA in the case of solar drying method revealed that the main effects of leaf size and drying time and also their interaction on the amount of evaporated water were all significant at the 1% level of probability (P<0.01). The effect of drying time and leaf size on the moisture ratio and the amount of evaporated water from meant leaves in solar drying methods is shown in Figures 3 and 4. With decreasing the size of meant leave
slices, the contact area between the leaves and drying airflow increases. Moreover, the meant leaves structure is cracked due to cutting the leaves by knife. This may cause an increase in the amount of evaporated water during drying process. At the same drying time, the amount of evaporated water for 1 cm slices was more than that of 5 cm slices because of the grater contact area provided on the leaves surface for moisture evaporation in the case of 1 cm slices. The amount of evaporated water from the 1 cm slices was totally 3.2% more than that of 5 cm slices. The rate moisture desorption from the mint leaves in solar drying method was high at the first times of drying and then the rate of desorption was decreased. As seen in Figure 3, more than 50% of samples moisture was desorbed at less than 2 hours. A similar trend was reported by Lotfalian et al. (2010a).

**Hot Air Drying Method**

Based on the ANOVA the effects of meant slice sizes and drying time and also their interaction effect of on the amount of evaporated water from the leaves were significant at the 1% level of probability (P<0.01) in hot air drying method. The effect of drying time and leaves slice sizes on the moisture ratio and the amount of evaporated water from the meant leaves in hot air drying method is shown in Figures 5 and 6. The moisture desorption trend in hot air drying method was similar to the traditional and solar drying methods. In hot air drying, because of eliminating the effect of sun ray variation during the experiments and providing constant temperature airflow by a combined heater and blower the drying trend is faster as compared with the traditional and solar drying methods. As observed in Figure 5, the amount of evaporated water from the samples, after 4 hours from beginning of experiments, is equal to the amount of water which was desorbed from the samples after 17 hours and 9 hours of drying processes in traditional and solar drying methods, respectively. It can be seen in Figure 5 that more than 50% of the samples moisture was desorbed in less than 75 minutes. Lotfalian et al. (2010b) reported similar results in the case of mint and dill.

In Figure 7 the effect of mint slices on the average amount of evaporated water from the samples at each 60 minutes for the three mentioned drying methods is illustrated. As shown, in all of the three methods decreasing the mint leaves slices caused the average amount of evaporated water and the total amount of moisture desorption to increase.
Microwave Drying Method

In microwave drying method because of high rate-low time drying trend existed, there was no significant difference between the leaves slices in drying process; whilst the effect of sampling time on the amount of evaporated water was significant at the 1% level of probability (P<0.01). The effect of drying time and leaves slice sizes on the moisture ratio and the amount of evaporated water from the meant leaves in microwave drying method is shown in Figures 8 and 9. As shown in Figure 8 more than 70% of samples moisture was desorbed after 45 s from the beginning time of the drying process. The qualitative assessment of the dried samples indicated that the samples aroma had been retained after microwave drying process; while the samples shrinkage in microwave drying method was higher than that of traditional, solar and hot air drying methods. Similar results were reported by Askari and Djomeh (2004), Funebo et al. (2000) and Prothon et al. (2002).

Qualitative Assessment of Dried Samples

The results of qualitative assessment of the samples dried with four drying methods of traditional, solar, hot air and microwave have been presented in Figure 10. The qualitative characteristics of mint leaves in the case of the samples had been dried in solar method was better that those of the other methods investigated. This was maybe due to the gradual drying trend existed in solar method. Mint leaves dried in traditional method had the lowest qualitative characteristics. In traditional drying method, mint leaves are subjected to dust, dirt and pollution which may cause the product quality to decrease after drying process.

The results revealed that smaller slices had lower qualitative characteristics than the larger sizes. This was maybe due to the fact that by decreasing the leaves size, the surface/volume ratio of the leaves decreased and subsequently may increase the enzymes activities on the leaves.
Modelling analysis of moisture desorption of mint leaves drying

Mathematical Drying Models

In Table 1 some standard mathematical drying models for thin-layer drying of mint leaves by different drying methods are presented. Among the models, “Varma et al”, “Two Term” and “Midili et al” models found to be the best models which explained thin-layer drying behavior of mint leaves for traditional drying ($R^2=0.9999$, RMSE=0.0058), hot air drying ($R^2=0.9999$, RMSE=0.0051) and solar drying ($R^2=0.9994$, RMSE=0.0077) methods, respectively. “Two Term” model was also found to be the best model expressing the thin-layer drying behavior of mint leaves in microwave drying ($R^2=0.9994$, RMSE=0.7691).

Conclusions

The following conclusions were drawn from the investigation and analysis of moisture desorption of mint leaves in different methods of the product drying.

The results of ANOVA indicated that the main effects of sample size and drying time on the amount of evaporated water were significant ($P<0.01$). In all of the drying methods evaluated, the 1 cm mint leave slices showed higher evaporation rate than that of 5 cm slices. Based on this result, mint leaves with smaller slices are recommended to be used in dryers for reducing the energy and time consumption during the product drying processes. The total time of drying in traditional, solar, hot air and microwave methods was 17 h, 9 h, 4 h and 45 seconds, respectively. The qualitative characteristics of mint leaves in the case of the samples had been dried in solar method was better than that those of the other methods investigated. This was maybe due to the gradual drying trend existed in solar method. Mint leaves dried in traditional method had the lowest qualitative characteristics. In traditional drying method, mint leaves are subjected to dust, dirt and pollution which may cause the product quality to decrease after drying process. The results also revealed that the smaller dried leaves had lower qualitative characteristics than the larger dried slices. Based on this result, it could be concluded that excessive size reduction may cause the mint leaves quality to decrease. Among the models evaluated, “Two Term” and “Varma et al” models found to the best explain thin-layer drying behaviour of mint leaves for traditional drying. “Varma et al”, “Two Term” and “Midili et al” models found to best explain thin-layer drying behaviour of mint leaves for traditional drying. For hot air drying and solar drying methods, “Two Term” model was also found to be the most suitable model expressing the thin-layer drying behavior of mint leaves in traditional drying.
Table 1  Assessment of the mathematical models had been used for thin layer drying of the samples.

<table>
<thead>
<tr>
<th>RMSE</th>
<th>$R^2$</th>
<th>Type of dryer</th>
<th>Model</th>
<th>Model name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0058</td>
<td>0.9991</td>
<td>Traditional</td>
<td>$MR=a \exp(-kt^a)+bt$</td>
<td>Midili et al</td>
</tr>
<tr>
<td>0.0077</td>
<td>0.9994</td>
<td>Solar dryer</td>
<td>$MR=a \exp(-kt^a)+(1-a)\exp(-gt)$</td>
<td>Verma et al</td>
</tr>
<tr>
<td>0.5964</td>
<td>0.5751</td>
<td>Hot Air</td>
<td>$MR=a \exp(-kt)$</td>
<td>Henderson and Pabis</td>
</tr>
<tr>
<td>0.8704</td>
<td>0.5239</td>
<td>Microwave</td>
<td>$MR=a \exp(-kt)+c$</td>
<td>Logaritmic</td>
</tr>
<tr>
<td>0.0574</td>
<td>0.9463</td>
<td>Traditional</td>
<td>$MR=a \exp(-kt)+b \exp(-kt)$</td>
<td>Two term</td>
</tr>
<tr>
<td>0.4970</td>
<td>0.9634</td>
<td>Solar dryer</td>
<td>$MR=\exp(-kt^a)$</td>
<td>Page</td>
</tr>
<tr>
<td>5.643</td>
<td>0.9998</td>
<td>Hot Air</td>
<td>$MR=\exp(-kt^a)$</td>
<td>Newton</td>
</tr>
</tbody>
</table>

$R^2$: Coefficient of determination; RMSE: Root Mean Square Error.
References


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