Quality Assurance and Safety of Crops & Foods, 2018; 10 (3): 269-276

Wageningen Academic
Publishers

Effect of air temperature on drying kinetics, colour changes and total phenolic content of sage leaves (*Salvia officinalis*)

İ. Doymaz[1*] and S. Karasu[2]

[1]Department of Chemical Engineering, Yildiz Technical University, Esenler, 34210 Istanbul, Turkey; [2]Department of Food Engineering, Yildiz Technical University, Esenler, 34210 Istanbul, Turkey; doymaz@yildiz.edu.tr

Received: 29 January 2018 /Accepted: 19 April 2018

RESEARCH ARTICLE

Abstract

The objective of the present study was to determine the influence of air temperature on the drying kinetics of sage leaves at temperatures of 45, 50, 55, 60, and 65 °C in a cabinet dryer. The drying time was significantly affected by temperature. Eight thin-layer drying models were used to describe the changes in moisture ratio as a function of time. The applicability of the models was determined regarding determination coefficient (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) values. The Midilli & Kucuk model showed the highest R^2, and lowest χ^2 and RMSE and was selected as the best model to describe drying characteristics of the sage leaves. Fick's second law was used to determine the effective moisture diffusivity (D_{eff}) at each temperature. D_{eff} values were significantly affected by temperature and ranged from 1.62×10^{-9} to 5.73×10^{-9} m^2/s. Temperature dependence parameters of D_{eff} was described by the Arrhenius equation. E_a value was 52.52 kJ/mol for the given temperatures. Drying temperature significantly affected total phenolic content (TPC) and antioxidant activity (AA). Highest TPC and AA values were found from the samples dried at temperature 45 °C. This study suggested that sage leaves should be dried at a lower temperature due to lower phenolic degradation and colour change.

Keywords: activation energy, effective moisture diffusivity, drying, mathematical modelling, sage leaves

1. Introduction

Sage (*Salvia officinalis*) is one of the important members of the mint family and has a considerable usage due to its strong aromatic smell. It is a fast growing evergreen plant. Sage is commonly used in medicine as a carminative, diuretic, antiheroic, analgesic, expectorant, and disinfectant (Hassanain, 2011). Besides its medicinal applications, it has gained commercial interest in food, pharmaceutical, and cosmetic industry. Furthermore, sage has been widely used as a herbal infusion (Pavlic *et al.*, 2017). Sage has a high moisture content and is a seasonal and highly perishable plant. Therefore, it should be subjected to preservation techniques, such as drying to provide consumption throughout the year (Kandil *et al.*, 2016).

Sage leaves are rich in phenolic compounds, such as carnosic acid, rosmarinic acid and caffeic acid, showing antiradical, antioxidant and antibacterial effects (Hamrouni-Sellami et al., 2013). It is recommended that the phenolic compounds remain at a maximum level during drying and extraction due to their proliferating and antioxidant properties (Loizzo *et al.*, 2014). Therefore, optimum process condition should be applied to obtain the maximum level of phenolic compounds.

Drying is one of the most widely used preservation techniques for long-term storage of plants. The principle of the drying process is to reduce water activity of the plant material in order to inhibit growth of microorganisms and to lower enzymatic activity, thereby extending shelf life at room temperature (Hamrouni-Sellami *et al.*, 2013). Another advantage of drying is that the material volume is reduced and packaging, handling, and transportation are facilitated.

Several studies were conducted to determine the effect of drying methods on the essential oil content of sage (Esturk, 2012; Hassanain, 2011; Venskutonis, 1997). Some studies

ISSN 1757-837X online, DOI 10.3920/QAS2017.1257

have reported on the drying behaviour of sage leaves (Belghit *et al.*, 1999; Esturk, 2012), however, the effect of different drying parameters on the effective moisture diffusivity (D_{eff}) and activation energy (*Ea*) of sage leaves have not been examined yet. In addition, there few studies on the effect of drying parameters on phenolic compounds of sage leaves (Sadowska *et al.*, 2017). The main objectives of this study were to investigate the effect of air temperature on drying behaviour, phenolic compounds and colour changes, to fit the experimental data to several thin-layer drying models, and to compute D_{eff} and *Ea* of sage leaves.

2. Material and methods

Material

Fresh sage (*Salvia officinalis* L.) leaves were obtained in September (2017) from a house garden in Arsuz, which is in the Southern region of Turkey. The initial moisture content of sage leaves was determined at 105 °C for 24 h using an oven. The moisture content analysis was carried out in three parallel runs with a mean value of 70.58%, wet basis (2.399 kg water/kg dry matter (d.b.)).

Experimental procedure

Sage leave samples were dried using a cabinet dryer (APV Pasilac Ltd., London, UK) as previously described by Doymaz (2004). The drying process was carried out at 45, 50, 55, 60 and 65 °C air temperatures and a constant air velocity of 2 m/s. Air velocity was determined by a Testo 440 vane probe anemometer (Testo, West Chester, PA, USA). The airflow is set to be horizontal to the drying surface of the leaves. Approximately 15 g of sample was put into the dryer. Moisture loss was recorded at 10 min intervals during drying. A digital balance (model BB3000; Mettler-Toledo AG, Grefensee, Switzerland) with 0.1 g accuracy was employed to record the sample weight. The drying process was finished when the sample weight reached a constant value. The final moisture content of the dried sage leaves was about 0.04 kg water/kg dry matter). After drying, the products were cooled and stored in a polyethylene bag at room temperature. The experiments were conducted in triplicate and the average values of the moisture content were used for plotting the drying curves.

3. Theoretical approach

Moisture content

The moisture content of sage leaves was determined using Equation 1:

$$M = \frac{W_i - W_d}{W_d} \tag{1}$$

where *M* is the moisture content (kg water/kg dry matter), W_i is the weight of the sample (kg), and W_d is the dry matter content of the sample (kg).

Drying rate

The drying rate of sage leaves was calculated at a particular period by Equation 2:

$$DR = \frac{M_{t_1} - M_{t_2}}{t_2 - t_1} \tag{2}$$

Where M_{t1} and M_{t2} are the moisture contents (d.b.) at times t_1 and t_2, respectively, and t_1 and t_2 represent drying times (min).

Drying kinetic models

Table 1 shows the kinetic models, which are often used for agricultural products, of thin-layer drying of sage leaves. It was assumed that mass transfer during the drying process is mostly controlled by a diffusion mechanism. The moisture ratio (MR) values were determined by Equation 3:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{3}$$

where *M* is the moisture content (kg water/kg dry matter), W_i is the weight of the sample (kg), and W_d is the dry matter content of the sample (kg). M_0, M_e and M_t are the initial moisture content, the equilibrium moisture content, the moisture content at t (kg water/kg dry matter), respectively. As M_e is very small compared to M_0 and M_t values, M_e can be neglected, and *MR* can be described as M_t/M_0 (Esturk, 2012; Ju *et al.*, 2016).

Table 1. Mathematical models used to represent the drying of sage leaves.[1]

Model name	Model	Reference
Lewis	$MR = \exp(-kt)$	Hossain *et al.* (2007)
Henderson & Pabis	$MR = a \cdot \exp(-kt)$	Jeguirim *et al.* (2017)
Logarithmic	$MR = a \cdot \exp(-kt) + c$	Doymaz (2009)
Page	$MR = a \cdot \exp(-kt^n)$	Esturk (2012)
Midilli & Kucuk	$MR = a \cdot \exp(-kt^n) + bt$	Midilli and Kucuk (2003)
Parabolic	$MR = a + bt + ct^2$	Sharma and Prasad (2004)
Wang & Singh	$MR = 1 + at + bt^2$	Kutlu Kantar and Isci (2017)
Aghbashlo *et al.*	$MR = \exp(-(at / 1 + bt))$	Aghbashlo *et al.* (2009)

[1] a, b, c, k, n empirical constants and coefficients in the drying models.

Statistical analysis

Experimental data were analysed using Statistica version 8.0.550 (StatSoft Inc., Tulsa, OK, USA). The model's parameters were calculated by a non-linear regression based on the Levenberg-Marquardt algorithm. The goodness of fit for each model was evaluated based on the statistical parameters, such as coefficient of determination (R^2), reduced chi-square (X^2) and root mean square error (RMSE) calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pre} - MR_{\exp,i}\right)^2} \tag{4}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \tag{5}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \tag{6}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental and predicted dimensionless moisture ratios, respectively; N is the number of observations; z is the number of constants. A higher R^2 value and lower X^2 and RMSE values indicate a better fit (Adiletta *et al.*, 2016; Kutlu Kantar and Isci, 2017).

Calculation of effective moisture diffusivity

The experimental drying data were fitted to Fick's second law of diffusion equation for the determination of effective moisture diffusivity coefficients.

$$\frac{\partial M}{\partial t} = D_{eff}\frac{\partial^2 M}{\partial x^2} \tag{7}$$

where M is the moisture content (kg water/kg dry matter), t is the drying time (s), and D_{eff} is the effective moisture diffusivity (m^2/s). Equation 7 can be used to determine the moisture ratio regarding infinite series by giving the analytical solutions for various regularly shaped bodies, such as rectangular, cylindrical, and spherical shapes, with the appropriate initial and boundary conditions shown as follows:

$$\begin{aligned} t &= 0, & 0 < x < L, & \quad M = M_0 \\ t &> 0, & x = 0, & \quad \frac{\partial M}{\partial t} = 0 \\ t &> 0, & x = L, & \quad M = M_0 \end{aligned} \tag{8}$$

The present case was considered of slab geometry, and then the first boundary condition described that moisture is initially uniformly distributed throughout the sample. The second described that the mass transfer is symmetric concerning the centre of the slab. The third condition showed that the surface moisture content instantaneously reaches equilibrium with the conditions of surroundings air (Zhang *et al.*, 2014).

The solution of diffusion Equation 7 for slab geometry is solved by Crank (1975) and supposed uniform initial moisture distribution, negligible external resistance, constant temperature and diffusivity, and negligible shrinkage:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\,exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \tag{9}$$

where D_{eff} is the effective moisture diffusivity (m^2/s), L is the half thickness of the slab (m), and n is the positive integer. Equation 9 can be further simplified to only the first term of the series and expressed in a logarithmic form for long drying periods:

$$ln\left(MR\right) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}t}{4L^2}\right) \tag{10}$$

D_{eff} was calculated from the slope (K) of a straight line by plotting experimental drying data regarding *ln* (MR) versus time according to Equation 10.

$$K = \frac{\pi^2 D_{eff}}{4L^2} \tag{11}$$

Estimation of activation energy

The effect of the air temperature on D_{eff} could be described by an Arrhenius-type equation (Onwude *et al.*, 2016):

$$D_{eff} = D_0\,exp\left(-\frac{E_a}{R(T + 273.15)}\right) \tag{12}$$

Here D_0 shows the pre-exponential factor (m^2/s), E_a represents the activation energy (kJ/mol), R and T respectively show the universal gas constant (kJ/(mol·K)) and temperature (°C).

Colour

The colours of the fresh and dried sage leaves were analysed with a chroma meter (CR-13, Konica Minolta, Tokyo, Japan) by taking measurements from four different surfaces. The colour values of the sage leaves were expressed as L (whiteness/darkness), a (redness/greenness), and b (yellowness/blueness). For determination of the overall colour change the total colour differences (ΔE) and Chroma values were determined. ΔE and Chroma values calculated by Equation 13 and 14, respectively:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{13}$$

$$C = \sqrt{a^2 + b^2} \tag{14}$$

Extraction of the phenolic compounds

Methanol:distilled water mixture (1:4, v/v) was used for extraction of the phenolic compounds of sage leaves. 5 g fresh and 0.5 g dried sage leaves were weighed and mixed with 100 ml methanol:water solution. Then, the mixed solution was homogenised using an Ultra-Turax (HG-15D; Daihan Scientific, Wonju-si, South Korea) at 10,000 rpm for 3 min. After homogenisation, the solution remained during 2 h at room temperature in a shaker for extraction. Finally, the extracts were centrifuged (Universal 320R; Hettich, Tuttlingen, Germany) at 4,500×*g* for 10 min and filtered through a Whatman No. 1 and 0.45-μm filter (Maidstone, UK). The filtered extracts were kept at 4 °C for further analysis.

The total phenolic content

The total phenolic content (TPC) analysis of the sage leaves was conducted according to the method reported by Singleton and Rossi (1965). Initially, 2.5 ml of 0.2 N Folin-Ciocalteu phenol reagent was added to 0.5 ml of the leaves extract and mixed with 2 ml of 7.5% Na_2CO_3. This mixture was kept for 20 min at ambient temperature in a light-free place. After incubation, the absorbance was recorded at the 760 nm using an UV-vis spectrophotometer (UV-1800; Shimadzu, Kioto, Japan). The TPC was expressed as Gallic acid equivalent.

Antioxidant activity

AA value was determined using the method described by Singh *et al.* (2002). 0.1 ml of the leaves extract, and 4.9 ml of 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution (0.1 mM in ethanol) was mixed and held at 25 °C for 30 min. Finally, the absorbance at 517 nm was recorded. AA was expressed as mmol/g Trolox.

4. Results and discussion

Analysis of drying curves

The effect of air temperature on drying curves of sage leaves is shown in Figure 1. As expected, the increase in drying temperature reduced the time for water removal of the sage leaves, consequently decreasing drying time. The drying times at air temperature of 45, 50, 55, 60 and 70 °C were found to be 240, 150, 120, 90 and 70 min, respectively. The drying rate increased 3.42 times with drying temperature increased from 45 to 65 °C. This could be explained higher heat and mass transfer rate at a higher temperature. The effect of temperature on drying behaviour of various vegetables has been investigated by some researchers (Belghit *et al.*, 1999; Doymaz, 2009; 2011; Esturk, 2012).

Drying rate

The change of drying rate as a function of drying time is presented in Figure 2. The figure shows that the drying rate was fast at the beginning of the drying process and decreased continuously with drying time. The decrease in drying rate with time could be explained by the reduction in the porosity of the samples caused by shrinkage. Shrinkage during the drying process increases the resistance to water movement towards the surface, and can cause a significant reduction in drying rate (Singh *et al.*, 2006). Similar results were reported from a study on tomato slices (Abano *et al.*,

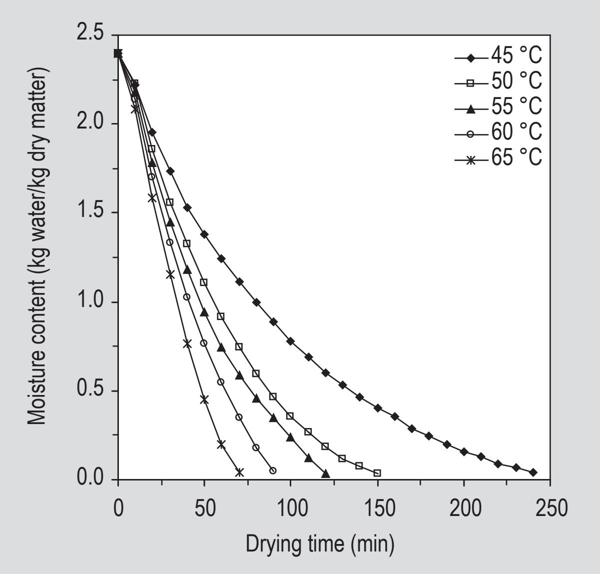

Figure 1. Variations of moisture content with drying time of sage leaves at different air temperatures.

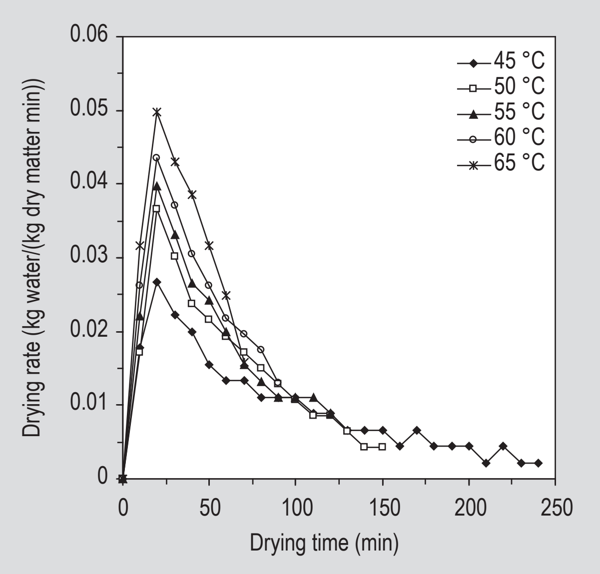

Figure 2. Variations of drying rate as a function of drying time at different air temperatures.

2014). It can be observed that the drying of sage leaves took place in the falling drying rate period as there is no constant drying rate period, thus indicating that the drying rate is controlled by liquid diffusion from interior parts of solid to surface (Arepally *et al.*, 2017). Our results are in agreement with other studies conducted on aromatic and medicinal plants (Belghit *et al.*, 1999; Doymaz, 2009; Ghnimi *et al.*, 2016).

Table 2. Statistical results obtained from the selected thin-layer drying models for sage leaves.

T (°C)	Model name	R^2	χ^2	Root mean square error
45	Lewis	0.9936	0.000549	0.096091
	Henderson & Pabis	0.9952	0.000430	0.078891
	Logarithmic	0.9995	0.000042	0.020106
	Page	0.9978	0.000198	0.058053
	Midilli & Kucuk	0.9996	0.000040	0.018920
	Parabolic	0.9953	0.000436	0.083733
	Wang & Singh	0.9935	0.000586	0.098611
	Aghbashlo *et al.*	0.9989	0.000096	0.037795
50	Lewis	0.9777	0.002356	0.163222
	Henderson & Pabis	0.9854	0.001654	0.133784
	Logarithmic	0.9976	0.000287	0.041877
	Page	0.9983	0.000191	0.044571
	Midilli & Kucuk	0.9993	0.000084	0.020237
	Parabolic	0.9960	0.000198	0.036752
	Wang & Singh	0.9979	0.000228	0.033382
	Aghbashlo *et al.*	0.9982	0.000204	0.028762
55	Lewis	0.9773	0.002433	0.137699
	Henderson & Pabis	0.9844	0.001815	0.117084
	Logarithmic	0.9975	0.000319	0.038467
	Page	0.9977	0.000259	0.040810
	Midilli & Kucuk	0.9989	0.000149	0.030636
	Parabolic	0.9974	0.000325	0.047459
	Wang & Singh	0.9971	0.000340	0.044926
	Aghbashlo *et al.*	09973	0.000317	0.043496
60	Lewis	0.9611	0.004578	0.168117
	Henderson & Pabis	0.9707	0.003872	0.155584
	Logarithmic	0.9973	0.000402	0.039186
	Page	0.9969	0.000402	0.044041
	Midilli & Kucuk	0.9994	0.000100	0.020655
	Parabolic	0.9980	0.000289	0.029660
	Wang & Singh	0.9971	0.000374	0.032120
	Aghbashlo *et al.*	0.9979	0.000278	0.032750
65	Lewis	0.9444	0.007365	0.189457
	Henderson & Pabis	0.9554	0.006890	0.186189
	Logarithmic	0.9952	0.000886	0.058260
	Page	0.9974	0.000387	0.040969
	Midilli & Kucuk	0.9998	0.000033	0.009752
	Parabolic	0.9962	0.000694	0.049456
	Wang & Singh	0.9947	0.000812	0.053226
	Aghbashlo *et al.*	0.9984	0.000242	0.023973

Evaluation of models

The calculated MR for various cases were analysed applying the eight thin-layer drying models identified in Table 1. Based on the highest R^2 value, minimum values of χ^2 and RMSE calculated for each drying condition, the best fitting models presenting the drying kinetics were chosen. The statistical parameters for the models are presented in Table 2. The R^2 values for all thin layer models were higher than 0.94. Among the eight thin-layer drying models tested, the Midilli & Kucuk model showed the highest R^2 and the lowest χ^2 and RMSE values for all temperature values, which were 0.9989-0.9998, 0.000033-0.000149 and 0.009752-0.030636, respectively. Figure 3 compares the experimental data with those predicted by the Midilli & Kucuk model for sage leaves. As shown, the predicted data is located on the straight line which exhibited the applicability of the Midilli & Kucuk model in defining the drying behaviour of sage leaves.

Effective moisture diffusivity

D_{eff} values of sage leaves were obtained for different drying temperatures by plotting ln (*MR*) against drying time and using the slope method. D_{eff} was calculated using Equation 11 and are given in Figure 4. The D_{eff} values increased significantly with increasing air temperature. The highest and the lowest D_{eff} values were found for 65 and 45 °C, respectively. The values of D_{eff} varied between 10^{-12} to 10^{-8} m^2/s and were within in general range for dried food materials (Zogzas *et al.*, 1996). The obtained D_{eff} values were comparable to those of dried spinach leaves (6.59×10^{-10} to 1.92×10^{-9} m^2/s in the temperature range of 50-80 °C (Doymaz, 2009), thyme leaves (1.09×10^{-9} to 5.99×10^{-9} m^2/s in the temperature range of 40-60 °C (Doymaz, 2011) and bay laurel leaves (1.21×10^{-10} to 5.27×10^{-10} m^2/s in the temperature range of 50-70 °C (Ghnimi *et al.*, 2016).

Activation energy

A plot of ln(D_{eff}) as a function of 1/(T+273.15) produced a straight line with a slope equal to $-E_a/R$, so E_a could be easily calculated (Figure 5). Equation 15 represents the effect of temperature on the D_{eff} of sage leaves with the following coefficients:

$$D_{eff} = 7.507\times10^{-1}\exp\left(-\frac{6347.3}{(T+273.15)}\right) \qquad (R^2 : 0.9604) \qquad (15)$$

The E_a value was found to be 52.52 kJ/mol for sage leaves. The obtained value of activation energy is within the general range of 12.7-110 kJ/mol for food materials (Zogzas *et al.*, 1996). The E_a value found in the present study was comparable with those for drying vegetable leaves: 73.84 kJ/mol for thyme leaves (Doymaz, 2011), 34.35 kJ/mol

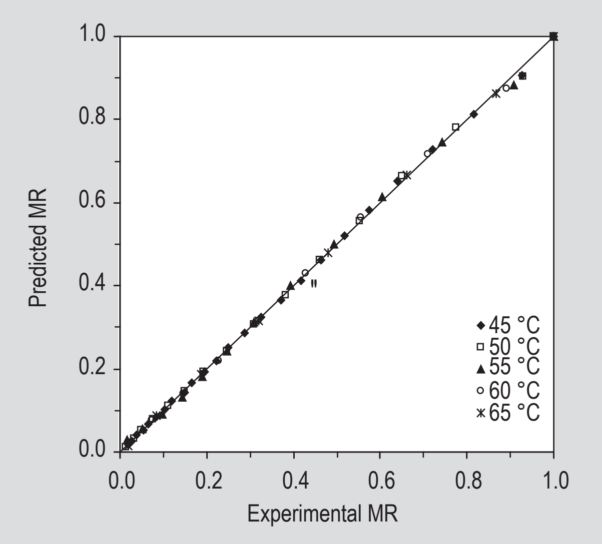

Figure 3. Experimental versus predicted moisture ratios (MR) using the Midilli & Kucuk model.

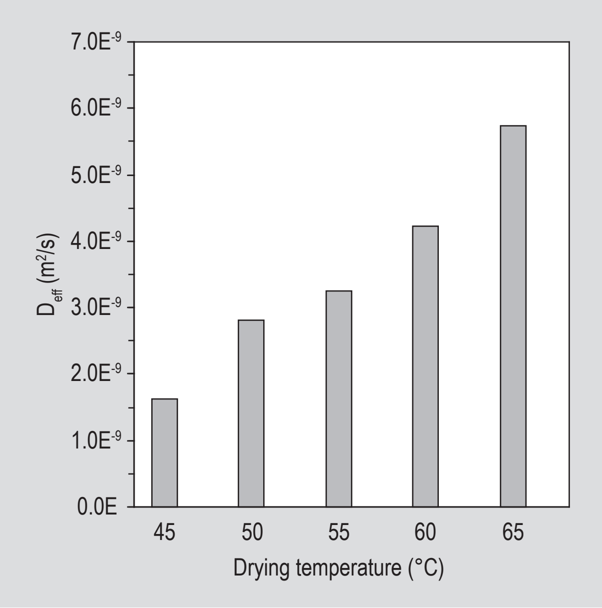

Figure 4. Variations of effective moisture diffusivity (D_{eff}) for sage leaves with different drying air temperatures.

for spinach leaves (Doymaz, 2009), and 51.44 kJ/mol for bay laurel leaves (Ghnimi *et al.*, 2016).

Colour evaluation

Colour usually is one of the most striking quality parameters affecting consumer expectancy of the product. The colour values of fresh sage leaves were 52.00, -6.81, and 12.95 for *L*, *a* and *b*, respectively. Table 3 shows the *L*, *a*, *b*, *ΔE*, and *C* values of the dried sage leaves. The various drying temperatures have a significant effect on the colour of sage leaves. *L* and *b* values of dried leaves decreased as the temperature increased. In contrast, as the temperature increased, the *a* values increased (Table 3). It is known that the variation in the whiteness of dried samples can be taken as a measurement of browning. The changes in *b* value may be due to decomposition of chlorophyll and carotenoid pigments, non-enzymatic Maillard browning, and formation of brown pigments. For temperatures increasing from 45 to 65 °C, Δ*E* increased from 13.05 to 20.36. Aidani *et al.* (2016) found that high temperatures are responsible for increasing Δ*E* values during drying of kiwifruit slices. The chroma (C) is a measure of chromaticity, which denotes the purity or saturation of the colour (Salehi and Kashaninejad, 2015). The C values showed a decrease during the drying process. C values varied from 4.82 to 2.99 at different temperatures and decreased when temperature increased (Table 3).

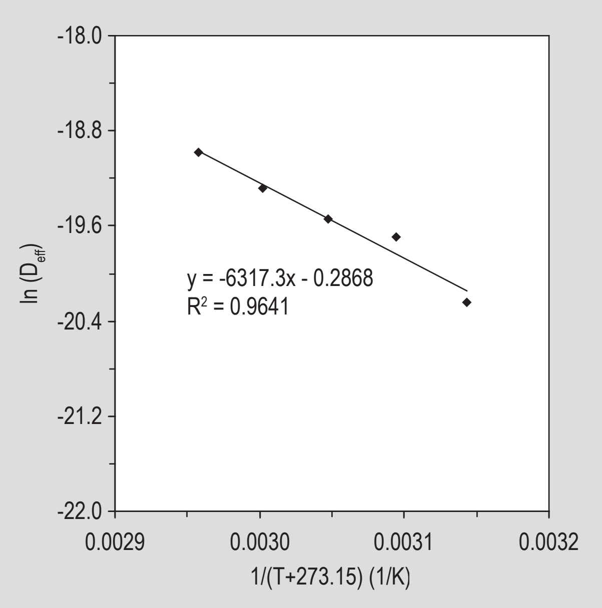

Figure 5. Arrhenius-type relationship between effective moisture diffusivity (D_{eff}) and reciprocal absolute temperature for sage leaves.

Effect of temperature on total phenolic compounds and antioxidant activity

Table 4 shows the effect of drying temperature on TPC and AA values. The TPC value of the fresh sage leaves was 35.81 mg/g. TPC value of the dried samples varied between 12.11 and 25.88 mg/g. Highest and lowest TPC were obtained from samples dried at 45 and 55 °C, respectively. As shown, the degradation of phenolic compounds was significantly affected by drying temperature (P<0.05). The degradation rate significantly increased when the drying temperature exceeded 50 °C. Similar results were reported by Sadowska *et al.* (2017). The higher degradation rate at high temperatures and long drying process could be explained by the heat-sensitive properties of some phenolic compounds, such as a carnosic acid. Carnosic acid is one

Table 3. Colour values for sage leaves dried at different temperatures.

Temperature (°C)	*L*	*a*	*b*	*ΔE*	*C*
45	47.74	0.45	4.80	13.05	4.82
50	45.08	0.54	4.36	14.46	4.39
55	41.27	0.62	4.00	16.85	4.04
60	40.33	0.72	3.37	17.85	3.44
65	37.72	1.41	2.64	20.36	2.99

of the predominant phenolic compounds found in sage leaves. Carnosic acid is an unstable compound and easily degraded during processes, such as extraction and drying (Milevskaya *et al.*, 2017).

The AA value of fresh sage leaves was 23 mmol/g Trolox. The AA showed a similar trend with the TPC (Table 4) and decreased with increasing drying temperature. The decrease in AA might be due to degradation of the phenolic compound during the drying process. The high correlation between AA and TPC is expected, because phenolic compounds are among main the compounds responsible for the antioxidant properties of plants. In conclusion, sage leaves should be dried at low temperature levels to preserve their heat-sensitive compounds and maintain their antioxidant activity.

5. Conclusions

Drying characteristics of sage leaves were investigated in a cabinet dryer at temperatures between 45-65 °C and a constant air velocity of 2 m/s. The air temperature had a significant effect on drying time and colour quality. The drying process was observed to take place entirely during the falling-rate drying period, and hence moisture migration to the surface is based on diffusion. The Midilli & Kucuk model gave the best representation of the drying data under all experimental conditions compared to the other tested models. The D_{eff} ranged from 1.62×10^{-9} m^2/s to 5.73×10^{-9} m^2/s with increasing drying temperature from 45 to 65 °C. The E_a for sage leaves was determined at 52.52 kJ/mol. This study suggests that sage leaves should be dried at a low temperature to prevent phenolic degradation and colour change.

Table 4. Total phenolic content (TPC) and antioxidant activity (AA) of sage leave samples dried at different temperatures.[1]

Temperature (°C)	TPC (mg/g)	AA (mmol/g Trolox)
45	25.58±0.25^{a}	18.08±0.65^{a}
50	21.36±0.15^{b}	16.51±0.36^{b}
55	12.11±0.09^{d}	11.65±0.42^{d}
60	14.64±0.08^{c}	12.86±0.29^{c}
65	15.17±0.11^{c}	12.05±0.35^{cd}

[1] The lower case letters in the same column show statistical difference (*P*<0.05).

References

Abano, E., Le Ma, H. and Qu, W., 2014. Thin-layer catalytic far-infrared radiation drying and flavour of tomato slices. Journal of Agricultural Engineering 45: 37.

Adiletta, G., Russo, P., Senadeera, W. and Di Matteo, M., 2016. Drying characteristics and quality of grape under physical pretreatment. Journal of Food Engineering 172: 9-18.

Aghbashlo, M., Kianmehr, M.H., Khani, S. and Ghasemi, M., 2009. Mathematical modelling of thin-layer drying of carrot. International Agrophysics 23: 313-317.

Aidani, E., Hadadkhodaparast, M. and Kashaninejad, M., 2016. Experimental and modeling investigation of mass transfer during combined infrared-vacuum drying of Hayward kiwifruits. Food Science and Nutrition 5: 596-601.

Arepally, D., Ravula, S., Malik, G. and Kamidi, V., 2017. Mathematical modelling, energy and exergy analysis of tomato slices in a mixed mode natural convection solar dryer. Chemical Science International Journal 20: 1-11.

Belghit, A., Kouhila, M. and C Boutaleb, B., 1999. Experimental study of drying kinetics of sage in a drying tunnel working in forced convection. Renewable and Sustainable Energy Reviews 2: 17-26.

Doymaz, I., 2004. Effect of pre-treatments using potassium metabisulphide and alkaline ethyl oleate on the drying kinetics of apricots. Biosystems Engineering 89: 281-287.

Doymaz, I., 2009. Thin-layer drying of spinach leaves in a convective dryer. Journal of Food Process Engineering 32: 112-125.

Doymaz, I., 2011. Drying of thyme (*Thymus vulgaris* L.) and selection of a suitable thin-layer drying model. Journal of Food Processing and Preservation 35: 458-465.

Esturk, O., 2012. Intermittent and continuous microwave-convective air-drying characteristics of sage (*Salvia officinalis*) leaves. Food and Bioprocess Technology 5: 1664-1673.

Ghnimi, T., Lamine, H. and Bagane, M., 2016. Experimental study of water desorption isotherms and thin-layer convective drying kinetics of bay laurel leaves. Heat and Mass Transfer 52: 2649-2659.

Hamrouni-Sellami, I., Rahali, F.Z., Rebey, I.B., Bourgou, S., Limam, F. and Marzouk, B., 2013. Total phenolics, flavonoids, and antioxidant activity of sage (*Salvia officinalis* L.) plants as affected by different drying methods. Food and Bioprocess Technology 6: 806-817.

Hassanain, A.A., 2011. Drying sage (*Salvia officinalis* L.) in passive solar dryers. Research in Agricultural Engineering 57: 19-29.

Hossain, M.A., Woods, J.L. and Bala, B.K., 2007. Single-layer drying characteristics and colour kinetics of red chilli. International Journal of Food Science and Technology 42: 1367-1375.

Jeguirim, M., Dutournié, P., Zorpas, A. and Limousy, L., 2017. Olive mill wastewater: from a pollutant to green fuels, agricultural water source and bio-fertilizer – Part 1. The drying kinetics. ACS Sustainable Chemistry Engineering 5: 8988-8996.

Ju, H.Y., El-Mashad, H.M., Fang, X.M., Pan, Z.L., Xiao, H.W., Liu, Y.H. and Gao, Z.J., 2016. Drying characteristics and modeling of yam slices under different relative humidity conditions. Drying Technology 34: 296-306.

Kandil, M.A.M., Sabry, R.M. and Ahmed, S.S., 2016. Influence of drying methods on the quality of sage (*Salvia officinalis*), parsley (*Petroselinum crispum*) and nasturtium (*Tropaeolum majus*). Research Journal of Pharmaceutical Biological and Chemical Sciences 7: 1112-1123.

Kutlu Kantar, N. and Isci, A., 2017. Drying characteristics of zucchini and empirical modeling of its drying process. International Journal of Food Studies 6: 232-244.

Loizzo, M.R., Abouali, M., Salehi, P., Sonboli, A., Kanani, M., Menichini, F. and Tundis, R., 2014. *In vitro* antioxidant and antiproliferative activities of nine *Salvia* species. Natural Product Research 28: 2278-2285.

Midilli, A. and Kucuk, H., 2003. Mathematical modeling of thin layer drying of pistachio by using solar energy. Energy Conversion and Management 44: 1111-1122.

Milevskaya, V.V., Temerdashev, Z.A., Butyl'skaya, T.S. and Kiseleva, N.V., 2017. Determination of phenolic compounds in medicinal plants from the *Lamiaceae* family. Journal of Analytical Chemistry 72: 342-348.

Onwude, D.I., Hashim, N., Janius, R.B., Nawi, N.M. and Abdan, K., 2016. Modeling the thin-layer drying of fruits and vegetables: a review. Comprehensive Reviews in Food Science and Food Safety 15: 599-618.

Pavlic, B., Teslic, N., Vidakovic, A., Vidovic, S., Velicanski, A., Versari, A., Radosavljevic, R. and Zekovic, Z., 2017. Sage processing from by-product to high quality powder: I. Bioactive potential. Industrial Crops and Products 107: 81-89.

Sadowska, U., Kopec, A., Kourimska, L., Zarubova, L. and Kloucek, P., 2017. The effect of drying methods on the concentration of compounds in sage and thyme. Journal of Food Processing and Preservation 41: e13286.

Salehi, F. and Kashaninejad, M., 2015. Effect of drying methods on rheological and textural properties, and color changes of wild sage seed gum. Journal of Food Science and Technology 52: 7361-7368.

Sharma, G.P. and Prasad, S., 2004. Effective moisture diffusivity of garlic cloves undergoing microwave-convective drying. Journal of Food Engineering 65: 609-617.

Singh, B., Panesar, P. and Nanda, V., 2006. Utilization of carrot pomace for the preparation of a value added product. World Journal of Dairy and Food Sciences 1: 22-27.

Singh, R.P., Murthy, K.N.C. and Jayaprakasha, G.K., 2002. Studies on the antioxidant activity of pomegranate (*Punica granatum*) peel and seed extracts using *in vitro* models. Journal of Agricultural and Food Chemistry 50: 81-86.

Singleton, V.L. and Rossi, J.A., 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. American Journal of Enology and Viticulture 16: 144-158.

Venskutonis, P.R., 1997. Effect of drying on the volatile constituents of thyme (*Thymus vulgaris* L) and sage (*Salvia officinalis* L). Food Chemistry 59: 219-227.

Zhang, Y.X., Chen, H.H. and Chen, T., 2014. Drying kinetics of RDX under atmospheric pressure and vacuum conditions. Energy Conversion and Management 80: 266-275.

Zogzas, N.P., Maroulis, Z. and Marinos-Kouris, D., 1996. Moisture diffusivity data compilation in foodstuffs. Drying Technology 14: 2225-2253.