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OPTIMIZATION OF DRYING AND OSMOTIC DEHYDRATION OF *Asparagus Officinalis* IN MICROWAVE AND CONVENTIONAL HOT AIR OVEN USING RESPONSE SURFACE METHODOLOGY

Cem Baltacıoğlu*

Food Engineering Department, Engineering Faculty, Omer Halisdemir University, Nigde, Turkey, 51240
**cembaltacioglu@gmail.com*

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ABSTRACT
The main objective to this study was to determine of the drying time of asparagus slices in hot air oven and microwave oven and to optimize drying time and effective moisture diffusivity was done in terms of process parameters. The drying time of asparagus slices varied from 140 to1485 min for hot air oven and from 75 to 2580 sec for microwave drying. Effective moisture diffusivity of asparagus was between from 0.20×10^{-10} m^2/s to 2.90×10^{-10} m^2/s for hot air oven and 8.89×10^{-10} m^2/s to 75.26×10^{-10} m^2/s for microwave oven. The results presented indicated that process parameters were significantly important on drying time and effective moisture diffusivity for hot air oven drying. The less drying time was obtained in microwave oven compare to hot air oven. Drying time was affected by the concentration of $CaCl_2$ and thickness of slice and effective moisture diffusivity was significantly influenced by the microwave power and slice thickness during microwave drying.

Keywords:
Drying;
Osmotic dehydration;
Effective moisture diffusivity;
Response surface methodology.

1. Introduction

Asparagus officinalis is a spring vegetable and the flowering perennial plant species in the genus *Asparagus* in the lily family, like its allium cousins, onions and garlic, it is native to most of Europe, northern Africa and western Asia (Grubben and Denton, 2004). Green asparagus vegetables contain flavonoids, amino acid derivatives, and sulfur containing acids, glycolic acid, tyrosine, vitamins, saponins and essential oils. In addition, it also contains fluathione with antioxidant and anticarcinogenic properties and the plant also contains diuretic and laxative properties and antioxidants, such as rutin which is an important percentage of the antioxidant activity in asparagus, ascorbic acid, tocopherol, ferulic acid and glutathione (Bliss, 1973; Duke and Ayensu, 1985; Leung, 1980; Tsushida, 1994). It is used to treat parasitic diseases, cancer (antitumor and antioxidative activity), neuritis and rheumatism (Duke, 1984; Li, 2002) and it can be used to treat cough, nose cancer, leukemia, lung cancer, breast cancer and lympthatic gland cancer (Je, 1999). In an in vitro study, hypotensive (Leung and Foster, 1996), antibacterial and antiviral effects of asparagus were declared (Pierce, 1999).

In osmotic dehydration process, vegetables or fruit slices immersed into highly osmotic solution, the water in the cells of the materials permeates into the osmotic solution through the cell membrane due to the high osmotic pressure and low water activity of the osmotic solution. Since osmotic dehydration is more economical than thermal drying methods, it is often used as a pretreatment for drying of biological materials (Pan et al., 2003). Osmotic dehydration method can be combined with other drying methods such as microwave and hot air oven. Microwave, relatively a new addition to the existing techniques, has been considered as a potential method for obtaining high quality dried food products, including fruits, vegetables and grains in this extent. Current studies have exhibited that drying of food material with microwave technology offers rapid, more uniform process and significant energy savings with a potential reduction in drying times of up to 50% and additionally avoiding undesired excessive surface temperature of treated material (Al-Harahsheh et al., 2009; Mcloughlin et al., 2003). Due to all these positive features of microwave drying some fruits and grains have been successfully dried by microwave technique and by a combination of microwave (Al-Harahsheh et al., 2009; Prasad, 2007; Prasad, 2006). Response surface methodology (RSM) is a statistical procedure frequently used for optimization studies. It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate problems. Equations describe the effect of test variables on responses, determine interrelationships among test variables and represent the combined effect of all test variables in any response. This approach enables an experimente to make efficient exploration of a process or system (Liyana-Pathirana and Shahidi, 2005). Therefore, RSM has been frequently used in the optimization of food processes (Eren and Kaymak-Ertekin, 2007; Corzo et al., 2008; Wani et al., 2008; Changrue et al., 2008; Mestgadh et al., 2008).

The aim of the study was to investigate drying of asparagus slices for two drying methods and to study the effects of slice thickness, microwave power, temperature of hot air oven and concentration of osmotic solution on drying time. In addition, optimization of drying time and effective moisture diffusivity was done in terms of process parameters by RSM.

2. Materials and methods

2.1. Sample Preparation

Fresh asparagus spears were supplied from market and stored in storage room at +4°C. The spears were thoroughly hand peeled prior to dehydration process and sliced to desired thickness by using an adjustable knife. All slices were sized in 30 mm 40 mm dimensions. Asparagus spears were sliced at 1, 2 and 3 mm in thickness and dried in the preheated oven to evaluate the influences of slice thickness on the drying characteristics of treated material. Initial moisture content of Asparagus was determined by placing spears in a conventional oven at 105°C till no further change in weight of sample was observed. The initial average moisture content of asparagus spears was determined as 94.19±0.89 %.

2.2. Osmotic Dehydration

For osmotic dehydration a solution of $CaCl_2$ was applied in a concentration of 0%, 20% and 40% w/w. Processing time was 60 min and constant bath temperature was 20°C. The ratio of material and osmotic solution is 1:10 w/w.

2.3. Drying

2.3.1.*Conventional Oven Drying*

Asparagus slices (2 mm in thickness) were placed into the preheated oven (Nüve, EN 400, Turkey) at air temperature of 70, 80, and, 90°C to evaluate the influences of temperature on drying process. Spears slices were spread as a single layer on the tray attached to the balance (KERN, EW-1500-2M with sensitivity of0.01g, Germany). During drying, weight of sample was recorded at a regular time interval. Drying process continued until desired moisture content was achieved (<10%, w/w).

2.3.2.*Microwave Drying*

A programmable domestic microwave oven (Samsung, MW71E, Malaysia) with maximum output of 800 W and wavelength of 2450 MHz was used for drying of slices. The dimensions of the microwave cavity were307x185x292 mm. Preweighed asparagus slices were spread in a glass dish (dried and weighed before use) as a single layer and placed on the center of microwave cavity. The sample was hold in the microwave oven under determined conditions. The samples were weighted taken out at every 60 s interval by switching off the microwave oven and after weight of sample was recorded, it was replaced in the oven. Drying process proceeded until desired moisture content was achieved (<10%, w/w). Three slice thicknesses (1, 2 and 3 mm) and three power level (100, 200 and 300 W) were examined to determine their effects on drying.

2.4. Effective moisture diffusivity

The effective moisture diffusivity (D_{eff}) was determined to obtain information about the mechanism of moisture transfer and the drying process. It was defined by Fick's second law with the assumption that diffusion is the only physical mechanism to control the transfer of water molecules to the surface. Asparagus slices prepared at different thicknesses were assumed to be an infinite slab, since other directions were large enough compared to the thickness. Thus, moisture movement was only throughout thickness. Fick's second law for moisture movement was solved with the following assumptions:

- The particle was homogenous and isotropic
- The material characteristics were constant, and the shrinkage was negligible
- Mass transfer was in one direction
- Moisture was initially uniformly distributed throughout the mass of a sample
- The pressure variations were negligible
- Evaporation occurred only at the surface
- Surface diffusion was ended, so the moisture equilibrium arises on the surface
- Effective moisture diffusivity was constant versus moisture content during drying
- Resistance to mass transfer at the surface was negligible compared to the internal resistance of the sample
- Mass transfer was represented by a diffusional mechanism the following analytical solution of Fick's second law proposed by Crank (1975) was used to calculate the effective moisture diffusivity.

$$MR = \frac{M_t - M_e}{M_i - M_e} = \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left(-\frac{(2i+1)^2 \cdot D_{eff} \cdot \pi^2}{4L^2}\cdot t\right) \tag{1}$$

where D_{eff} is the effective moisture diffusivity (m^2s^{-1}), L is the half thickness (drying from both sides) of the slab (m), MR is the fractional moisture ratio, t is the drying time (s), M_t is the moisture content of the material at any time, t; M_i is the initial moisture content of the material before drying and M_e is the equilibrium moisture content of a dehydrated asparagus slices, all moisture content values are in dry basis.

For long-term drying, only the first term of Eq.(1) was used to explain the drying procedure. The equilibrium moisture content (M_e) was assumed to be zero for microwave-assisted drying. The final equation to calculate the D_{eff} was as follows:

$$MR = \frac{M_t}{M_i} = \frac{8}{\pi^2} \exp\left(- \frac{D_{eff} \cdot \pi^2 \cdot t}{4L^2} \right) \quad (2)$$

Further simplification of Eq. (2) resulted in a straight-line equation as Eq. (3);

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{D_{eff} \cdot \pi^2}{4L^2} \cdot t\right) \quad (3)$$

The effective moisture diffusivity was calculated by fitting Eq. (3) to the curve of ln(*MR*) vs. time (Figure 1 and 3), and the results are presented in Tables 1 and 3.

2.5. Experimental Design

Response Surface Methodology (RSM) was used to optimize drying and dehydration conditions. Box-Behnken model was selected for RSM analysis. Box-Behnken design requires three levels, coded as -1, 0, +1. The effect of three independent process parameters: thickness (X_1, mm), concentration of dehydration solution of $CaCl_2$ (X_2, %), applied microwave power (X_3, W) in microwave drying or oven temperature (X_3, °C) in hot air oven on weight of sample as dependent variables were investigated using RSM. The total number of microwave and oven drying experiments were 30, three replicates at the center point of design were done. Minitab 17.0 was used for the experimental design, data analysis and regression modeling. The independent variables were; X_1 (1, 2, 3 mm), X_2 (0, 20, 40 %), X_3 (100, 200, 300 W) in microwave drying and X_1 (1, 2, 3 mm), X_2 (0, 20, 40 %), X_3 (70, 80, 90°C) in hot air oven drying. The proposed model was as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_{11} + b_{22}X_{22} + b_{33}X_{33} + b_{12}X_{12} + b_{13}X_{13} + b_{23}X_{23} \quad (4)$$

where *Y* was the response of equation, b_0 was the constant coefficient, $\boldsymbol{b_1, b_2, b_3}$ were the linear coefficients, $\boldsymbol{b_{11}, b_{22}, b_{33}}$ were the quadratic coefficients, $\boldsymbol{b_{13}, b_{23}, b_{12}}$ were the interaction coefficients. The values of R^2, adjusted-R^2, and lack-of-fit of models were evaluated to check the model adequacies.

3. Results and discussions

The study was designed to evaluate drying conditions of *Asparagus officinalis* slices and to optimize the process conditions using response surface methodology (RSM). Drying time (DT) and effective moisture diffusivity (D_{eff}) were investigated for dried asparagus slices. Models developed by RSM to predict the experimental results determined for each interested response. Multiple linear analysis of experimental data yielded second order polynomial models for predicting DT and D_{eff}. Analysis of variance (ANOVA) was conducted to determine significant effects of process variables on each response and to fit second-order polynomial models to the experimental data. Regression equation coefficients of the proposed models and statistical significance of all main effects calculated for each response were obtained. The effects that were not significant ($p \geq 0.05$) were shown in Table 2 and 4. The ANOVA tables also showed that lack of fit was not significant for all response surface models at a 95% confidence level. On the other hand, R^2 and $Adj\text{-}R^2$ were calculated to check the model adequacy as a lack of fit ≥ 0.05; $R^2 \geq 0.95$; and $Adj\text{-}R^2 \geq 0.88$ (Tables 2 and 4).

Table 1. Experimental design of hot air oven drying and corresponded responses (drying time and effective moisture diffusivity)

RunOrder	X_1	X_2	X_3	DT (min)		D_{eff} (m^2/sec) x 10^{10}	
	Oven Temp. (°C)	$CaCl_2$Concentartion (%)	Thickness of slice (mm)	Observed	Predicted	Observed	Predicted
1	80	0	3	1015	1041.30	1.80	1.71
2	70	20	3	1485	1406.92	0.95	0.94
3	80	20	2	715	740.77	1.40	1.42
4	80	40	1	455	455.05	1.30	1.28
5	90	20	3	510	600.67	2.90	2.84
6	90	0	2	490	462.45	2.40	2.41
7	90	40	2	400	314.95	2.60	2.61
8	70	40	2	1110	1121.20	0.75	0.73
9	70	0	2	1280	1268.70	0.50	0.48
10	80	40	3	820	893.80	1.95	1.96
11	90	20	1	140	161.92	2.10	2.09
12	80	20	2	710	740.77	1.40	1.42
13	80	0	1	590	602.55	1.00	0.98
14	70	20	1	890	968.17	0.20	0.22
15	80	20	2	910	740.77	1.40	1.42

Table 2. Regression coefficients of predicted models for the investigated responses of hot air oven drying

Variables	Coefficients	
	DT (min)	D_{eff} x10^{10} (m^2/s)
b_0	5120	-79.4
b_1	929^{*+}	13.8^{*+}
b_2	-10.5^{*}	0.75^{*+}
b_3	-93.4^{*+}	-5.63^{*+}
b_{11}	-61^{ns}	4.37^{*}
b_{22}	0.007^{ns}	0.01719^{*+}
b_{33}	0.390^{ns}	0.0938^{*+}
b_{12}	-0.75^{ns}	-0.1875^{*}
b_{13}	-5.62^{ns}	0.125^{ns}
b_{23}	0.1^{ns}	-0.00625^{ns}
R^2	97.96	99.97
Adj-R^2	94.28	99.92
Lack of fit	0.842	0.863

^{ns}not significant $p \geq 0.05$; * significant at $p<0.05$; $^{+}$ significant at $p<0.01$

Table 3. Experimental design of microwave oven drying and corresponded responses (drying time and effective diffusivity)

RunOrder	X_1	X_2	X_3	DT (sec)		D_{eff} (m^2/sec) x 10^{10}	
	MW Power (Watt)	$CaCl_2$ Concentration (%)	Thickness of slice (mm)	Observed	Predicted	Observed	Predicted
1	200	40	1	120	43.13	35.64	34.8365
2	300	40	2	150	376.88	67.65	64.6111

3	200	20	2	420	290.00	48.88	47.2870
4	300	20	1	75	75.00	57.71	61.5684
5	300	20	3	180	153.75	72.49	74.6491
6	200	40	3	450	249.37	48.04	48.9237
7	200	0	1	450	650.63	40.80	39.9213
8	100	20	1	1020	1046.25	8.89	6.7359
9	200	20	2	240	290.00	47.66	47.2870
10	100	20	3	1350	1500.00	27.97	24.1266
11	200	20	2	210	290.00	45.31	47.2870
12	200	0	3	1050	1126.88	55.49	56.3055
13	100	40	2	750	800.63	10.41	13.3876
14	300	0	2	360	309.37	75.26	72.2984
15	100	0	2	2580	2353.13	15.12	18.1669

Table 4. Regression coefficients of predicted models for the investigated responses of microwave oven drying

Variables	Coefficients	
	DT (sec)	D_{eff} x10^{10} (m^2/s)
b_0	3734	- 47.5
b_1	503^{ns}	15.62^{*+}
b_2	- 78.9^{*+}	0.072^{ns}
b_3	- 25.27^{*+}	0.4602^{*+}
b_{11}	- 38^{ns}	- 1.32^{ns}
b_{22}	0.664^{ns}	- 0.00243^{ns}
b_{33}	- 0.000420^{*}	- 0.000420^{ns}
b_{12}	- 3.37^{ns}	- 0.029^{ns}
b_{13}	- 0.0108^{ns}	- 0.0108^{ns}
b_{23}	0.2025^{*}	- 0.00036^{ns}
R^2	95.59	98.65
Adj-R^2	88.64	96.21
Lack of fit	0.139	0.115

^{ns}not significant $p \geq 0.05$; * significant at $p<0.05$; $^{+}$ significant at $p<0.01$

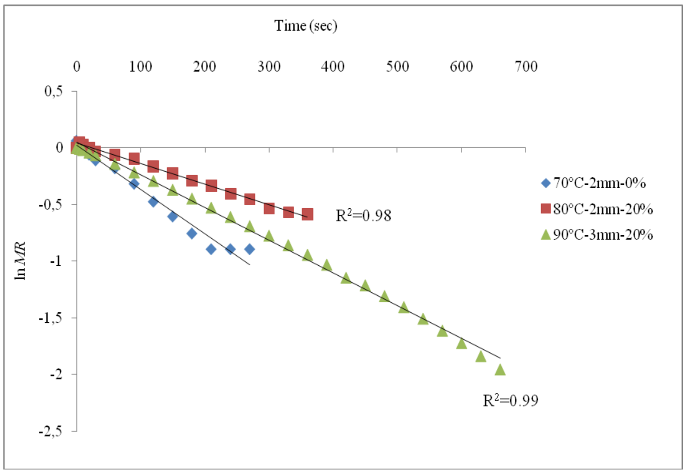
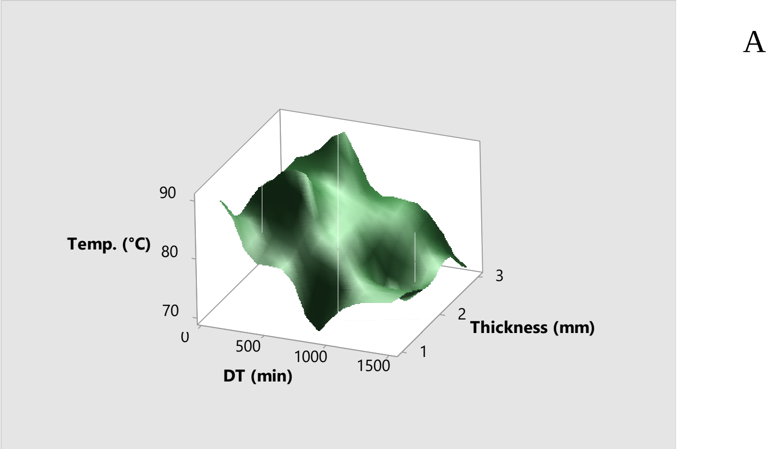


Figure 1. Linear relation between ln MR and drying time (sec) of asparagus slices and fitted proposed model for hot air oven drying R^2 = 0.97



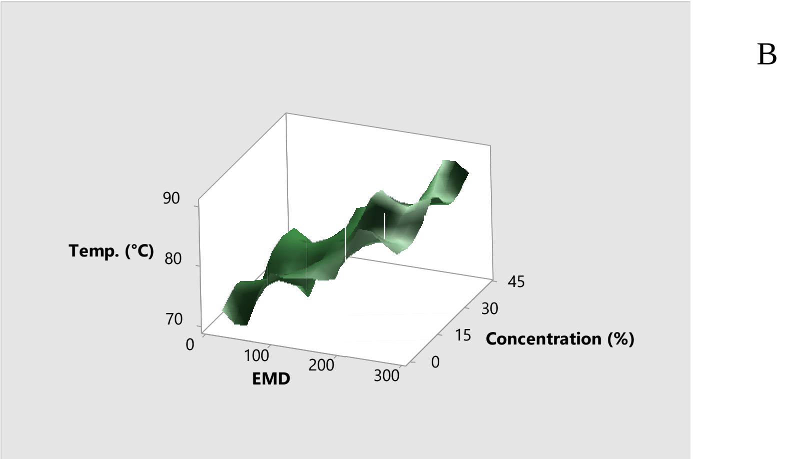


Figure 2. Response surface plot for the interaction effects of oven temperature and slice thickness on drying time (A). Response surface plot for the interaction effects of oven temperature and concentration of $CaCl_2$ one ffective moisture moisture diffusivity (B)

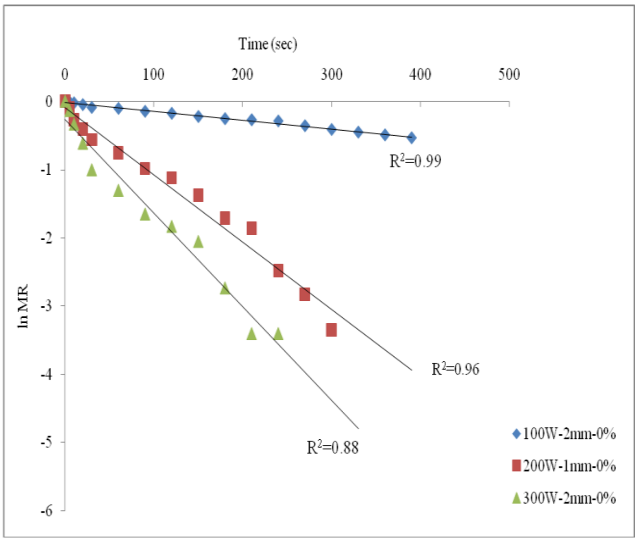


Figure 3. Linear relation between ln MR and drying time (sec) of asparagus slices and fitted proposed model for microwave oven drying

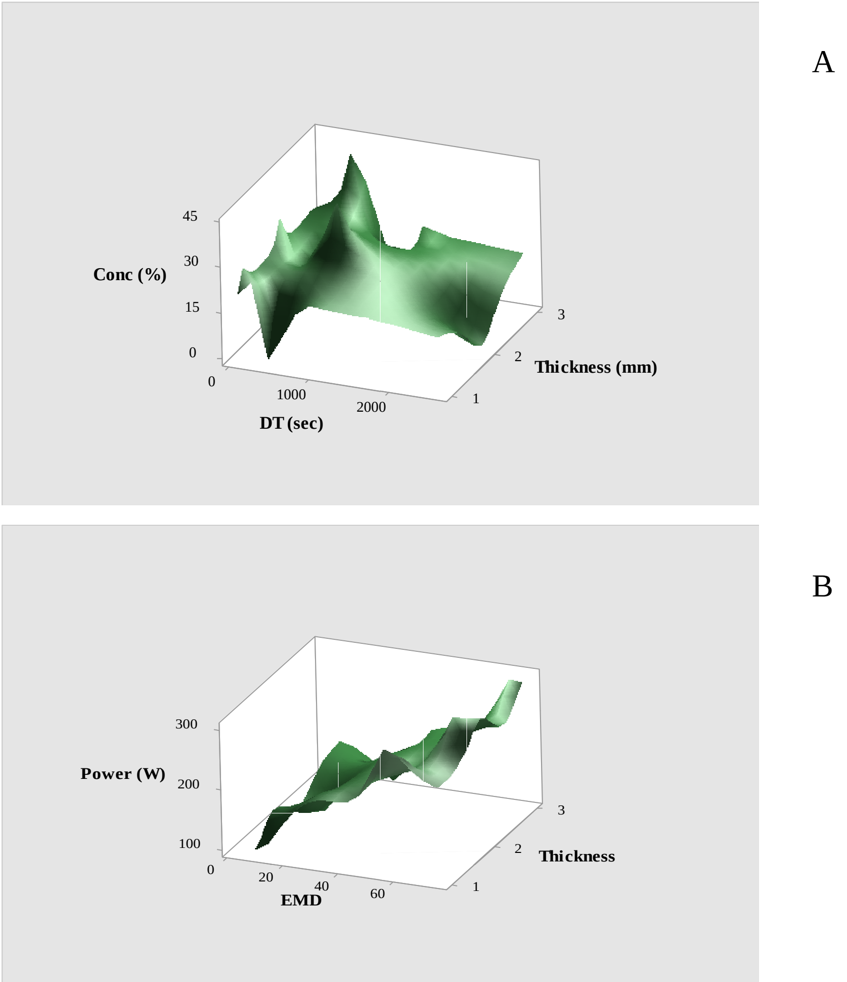


Figure 4. Response surface plot for the interaction effects of concentarion of $CaCl_2$ and slice thickness on drying time (A). Response surface plot for the interaction effects of microwave power slice thickness on effective moisture moisture diffusivity of asparagus slice (B)

3.1 Oven Drying

Temperature of hot air oven, concentration of $CaCl_2$ and thickness of asparagus slice were independent variables in this study. Observed and predicted values of DT and D_{eff} for hot air oven drying were given in Table 1. Temperature of hot air oven, concentration of $CaCl_2$ and thickness of asparagus slice were statistically important ($p<0.05$) on DT and D_{eff}. DT was increased with decreasing drying temperature. The highest DT value of asparagus slice was measured as 1485 min at 70°C oven temperature. The DT decreased as hot air oven temperature increased due to difference between temperature of sample and hot air (Figure 2). The influences of interaction between process factors (thickness of slice, temperature of oven and concentration of $CaCl_2$) were found insignificant (Table 2). Fitted model for drying time of asparagus slices was shown in Eq.5. Experimental results displayed high performance to predict drying time of asparagus slices within the studied range. Regression coefficient (R^2) and adjusted regression ($Adj\text{-}R^2$) coefficient of DT were calculated as 0.97, 0.94, respectively (Table 2).The model equation of DT was shown in Eq. 5. Figure 1 shows ln MR versus time (sec) in different values of oven temperature, slice thickness and concentration of $CaCl_2$. Pan et al. (2003) and Silva et al.

(2012) studied the effect of osmotic pretreatment before conventional drying of some fruit and vegetables. Reduction in total drying time by the application of osmotic pretreatment was reported.

The D_{eff} was calculated and used as an index of the rate of the drying process. The D_{eff} of a food material characterizes its intrinsic mass transfer properties of moisture (Karathanoset al., 1990). Increasing the D_{eff} was expected with temperature of hot air oven. Observed and predicted values of D_{eff} were given in Table 1. The fitted response surface plots and their corresponding contour plots for Dt and D_{eff} values of asparagus slices were given in Figure 2A/B. D_{eff} values of asparagus slices increased with oven temperature and concentration of $CaCl_2$ solution. Oven temperature, thickness of slice and $CaCl_2$ concentration were statistically important on D_{eff} values ($p<0.05$). Regression coefficient (R^2) and adjusted regression ($Adj\text{-}R^2$) coefficient of D_{eff} were evaluated as 0.99, 0.99, respectively (Table 2). The model equation of D_{eff} of asparagus slices was shown in Eq. 6. The D_{eff} for asparagus slices varied from 0.50 to 2.90 ($\times 10^{-10}$, m^2/s) for the different oven temperature, $CaCl_2$ concentration and slice thickness. The values lie within the general range of 10^{-11}–10^{-9} m^2/s for food materials (Zogzas et al., 1996). According the results of ANOVA of D_{eff}, slice thickness, $CaCl_2$ concentration and oven temperature affect the D_{eff} values of asparagus when hot air oven was used for drying. For experimental determination of effective moisture diffusivity in convective drying, the D_{eff} values increased from 1.45×10^{-10} to 10.3 $\times 10^{-10}$ m^2/s with temperature increases from 50 to 80°C (Erenturk et al., 2010).

Drying time (min) = $5120 - 93.4X_1 - 10.5X_2 + 929X_3 + 0.390X_1X_1 + 0.007X_2X_2 - 61.0X_3X_3 + 0.100\,X_1X_2 - 5.62\,X_1X_3 - 0.75\,X_2X_3$ (5)

Effectivemoisturediffusivity ($\times 10^{-10}$, m^2/s) = $-79.4 - 5.63\boldsymbol{X_1} + 0.750\boldsymbol{X_2} + 13.8\boldsymbol{X_3} + 0.0938\boldsymbol{X_1X_1} + 0.01719\boldsymbol{X_2X_2} + 4.37\boldsymbol{X_3X_3} - 0.00625\boldsymbol{X_1X_2} + 0.125\boldsymbol{X_1X_3} - 0.1875\boldsymbol{X_2\,X_3}$ (6)

3.2 Microwave Drying

Microwave drying was used in this study to investigate the usage of microwave on DT and D_{eff}. Reducing the DT for microwave drying was expected compare to hot air oven. DT values of asparagus decreased with increase in power level of microwave oven and thickness of slice. Less DT means less energy requirements for the drying process. DT values varied from 75 to 2580 sec for the different microwave powers, $CaCl_2$ concentrations and slice thickness'. The lowest value vas observed at 300W microwave power level, 1 mm thickness of slice and 20% $CaCl_2$ solution. Drying results are shown in Table 3 in terms of DT and D_{eff}. Slice thickness and concentration of $CaCl_2$ are significantly important on DT values ($p<0.05$). The interaction between factors of experiment (thickness of slice, microwave power and concentration of $CaCl_2$) were shown in Table 4 and only thickness and thickness factor significant on drying time ($p<0.05$). Square parameters of asparagus slice that is concentration of $CaCl_2$ and thickness of slice was statistically important ($p<0.05$) on DT. Ahrne et al. (2003) compared textural effects of two Ca pretreatments before microwave drying of apples and potatoes. Ca pretreatments influenced the strength of the plant tissue and producing products of hardness after rehydration. For apples and potatoes Ca pretreatments at 20°C increased the hardness of rehydrated samples compared with untreated ones. Figure 3 shows ln MR versus time (sec) in different values of microwave power, slice thickness and concentration of

$CaCl_2$). The model equation of DT was shown in Eq. 7. Regression coefficient (R^2) and adjusted regression ($Adj\text{-}R^2$) coefficient of DT were calculated as 0.95, 0.88, respectively (Table 4). Funebo et al. (2002) described microwave assisted drying for apple and mushroom and the drying time for apple and mushroom was reduced with the use of microwave oven. In addition, drying time of banana slices was decreased by about 64% in a study (Maskan, 2001).

The ranges and independent variables levels are shown in Table 4. Increasing the D_{eff} was desirable microwave process to drying the asparagus slices. D_{eff} values varied from 8.893 to 75.267 ($\times 10^{-10}$, m^2/s) for different drying conditions. D_{eff} values increased with studied parameters of asparagus drying. According to the results of ANOVA of D_{eff} microwave power and slice thickness were significantly affected ($p<0.05$) the D_{eff} values of asparagus slices whereas $CaCl_2$ pretreatment before drying was not affected D_{eff} values. Regression coefficients of predicted models for the drying responses of microwave oven drying of asparagus slices were given in Table 4. Fitted equation for D_{eff} value was shown in Eq.8 and the coefficients of fitted model were shown in Table 4. Regression coefficient (R^2) and adjusted regression ($Adj\text{-}R^2$) coefficient of D_{eff} were calculated as 0.98, 0.96, respectively (Table 4). The effects of process variables on DT and D_{eff} of asparagus slices are shown in Figure 4A/B. D_{eff} values of asparagus slices increased with microwave power and thickness of slice. Dak and Pareek (2014) studied the effect of microwave drying on D_{eff} of pomegranate and an increase of D_{eff} was clarified with increasing the microwave power. D_{eff} values increased with decreased in moisture content under drying conditions (Prasad, 2006).

$$\textbf{Drying time (sec)} = 3734 - 78.9\, X_2 + 503\, X_3 - 25.27\, X_1 + 0.664\, X_2X_2 - 38\, X_3X_3 + 0.0404\, X_1X_1 - 3.37\, X_2X_3 + 0.2025\, X_2X_1 - 0.56\, X_3X_1 \quad (7)$$

$$\textbf{Effectivemoisturediffusivity}(\mathbf{x10^{-10}, m^2/s}) = -47.5 + 0.072X_2 + 15.62X_3 + 0.4602X_1 - 0.00243X_2X_2 - 1.32\, X_3X_3 - 0.000420X_1X_1 - 0.029X_2X_3 - 0.00036X_2X_1 - 0.0108X_3X_1 \quad (8)$$

4. Conclusions

In this study, the effect of slice thickness, power level/hot air oven temperature and concentration of $CaCl_2$ on the DT and D_{eff} values of asparagus slices were investigated. DT of asparagus slices decreased with the increase in microwave power and slice thickness for microwave oven and hot air oven. In addition, D_{eff} values of samples increased with temperature of oven and thickness of slices for hot air oven drying and power level and slice thickness for microwave oven drying. RSM was used to optimize the factors in order to obtain DT and maximum D_{eff} values of asparagus slices for drying in hot air oven and microwave oven. The lowest DT was observed as 400 min in 90°C of oven temperature, 40% of $CaCl_2$ concentration and 2 mm of slice thickness for hot air oven. In addition, 300 W of power level, 20% of $CaCl_2$ concentration and 1 mm of slice thickness gave the lowest DT for microwave oven. The highest D_{eff} value of asparagus slices hot air oven and microwave oven were measured as 2.90×10^{-10} m^2/s at 90°C oven temperature, %20 of $CaCl_2$, 3 mm slice thickness and 75.26×10^{-10} m^2/s at 300 W power, 0 % $CaCl_2$ and 2 mm slice thickness, respectively. When the two drying methods were examined lower DT and higher D_{eff} value were obtained in microwave oven drying of asparagus slices.

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