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Comparison of the microwave drying kinetics of culture and natural asparagus

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ABSTRACT. Asparagus (*Officinalis kültür* or *Acutifolius natural*) is an healthy food, which can be cooked or eaten raw. In this study, the microwave drying kinetics along with the color evaluation and volumetric decrease values of culture and natural asparagus are studied. For culture and natural asparagus the drying times were found as 42, 13, 10 min. and 36, 7 and 5.5 min. for at the microwave power levels of 90, 180 and 360W, respectively. Four different drying models were applied and showed that the Alibas model best fits the data. The effective moisture diffusivity values were calculated between 3.78×10^{-07} and 1.54×10^{-06} m^2 s^{-1} for culture and 4.58×10^{-07} and 4.00×10^{-06} m^2 s^{-1} for natural asparagus. The activation energies were found as 20.967 kW kg^{-1} and 146.020 kW kg^{-1} for culture and natural asparagus, respectively. For the color analysis, the optimal power level was found as 90 W.

Keywords: activation energy; asparagus; color analysis; effective moisture diffusivity; microwave drying; volume decrease.

Comparação da cinética de secagem por microondas da cultura e espargos naturais

RESUMO. Aspargus (*Officinalis kültür ou Acutifolius natural*) é um alimento saudável, que pode ser cozido ou comido cru. Neste estudo, estudou-se a cinética de secagem por microondas, juntamente com a avaliação da cor e os valores de retração volumétrica da cultura e dos espargos naturais. Para a cultura e aspargos naturais, os tempos de secagem foram encontrados em 42, 13, 10 min. e 36, 7 e 5.5 min. para os níveis de potência de microondas de 90, 180 e 360W, respectivamente. Foram aplicados quatro modelos de secagem diferentes e mostraram que o modelo Alibas se encaixa melhor nos dados. Os valores efetivos da difusividade da umidade foram calculados entre 3.78×10^{-07} e 1.54×10^{-06} m^2 s^{-1} para a cultura e 4.58×10^{-07} e 4.00×10^{-06} m^2 s^{-1} para aspargos naturais. As energias de ativação foram encontradas como 20.967 kW kg^{-1} e 146.020 kW kg^{-1} para cultura e aspargos naturais, respectivamente. Para a análise de cores, o nível de potência ideal foi encontrado como 90 W.

Palavras-chave: energia de ativação; aspargos; análise de cores; difusividade efetiva da umidade; secagem por microondas; diminuição de volume.

Introduction

Asparagus species, belonging to the family Liliaceae or asparagaceae, are native medicinal shrubs valued for their medicinal properties such as. The genus Asparagus includes about 300 species around the world (Negi, Singh, Joshi, Rawat, & Bisht, 2010).

Asparagus acutifolius, common name wild asparagus, is an evergreen perennial plant belonging to the genus Asparagus. The Latin name *acutifolius* of this species, meaning "thorny leaves", derives from the characteristic shape of the leaves, a quite common feature in the typical plants of the Mediterranean and Aegean**.** *Asparagus acutifolius* is a tertiary genetic relative of cultivated Asparagus (*A. officinalis*) and so it has potential as a gene donor for crop improvement. In other words, *Asparagus officinalis* L. is a primary wild relative of cultivated Asparagus (*A. officinalis*) (United States Department of Agriculture [USDA], 2013).

This medicinal herb, Latin name is *Asparagus officinalis* L. (culture) and *Asparagus acutifolius* (wild), has many benefits in terms of health. Due to the vitamin and mineral content, asparagus is used in many countries since ancient times because it is beneficial against diseases. Asparagus is a very important plant of traditional medicine. They possess a variety of biological properties, such as being antioxidants, immunostimulants, anti-inflammatory, antihepatotoxic, antibacterial, antioxytocic, and reproductive agents. It is used as anti-cancer herbal medicine and blood purifier. Several tonics like energetic tonics and medicines to relieve hypertension, anaemia and to improve digestion are prepared from asparagus (Nindo, Sun, Wang, Tang, & Powers, 2003; Negi et al., 2010). Asparagus has high respiratory activity even after harvesting so it deteriorates rapidly which results in very short shelf life at the room temperature (An, Zhang, Wang, & Tang, 2008).

Asparagus (*Asparagus officinalis* L.) is a high-value, labour intensive, perennial vegetable, and it is described as a gourmet product. The vegetable is sold in three type of products like fresh spears, frozen spears and canned spears. White and green spears can be harvested and green spears consumed mainly as fresh. Recently, developed countries fresh asparagus demand is all year round and this necessity brings out new cultivation methods (Akan, 2014). China is the largest producer and consumer in the world while Peru is the world's leading exporter. The Food and Agriculture Organization of the United Nations (FAOSTAT) statistical data showed that the yield of asparagus worldwide is about 7.9 million tons; the major producer countries are China, Peru, Italy, Mexican and Spain. Turkey produced 68 tons in 2014 (FAO, 2014).

Drying processes has been used in the food industries for efficient long-term preservation of final products. In order to avoid the microbial spoilage the fresh water inside the food products must be removed. This removal process can easily be done by the drying methods. The most used method for the drying of food products are hot-air, which has so many disadvantages majorly lower energy efficiency, longer drying times during the falling rate period and quality loss (Calin- Sánchez, Figiel, Wojdylo, Szaryez, & Carbonell-Barrachina, 2014; Pan et al. 2008, Doymaz, Kipcak, & Piskin, 2015; Kipcak 2017).

For the last two decades, microwave method has the attraction as an alternative method for drying several food products such as vegetables and fruits. In microwave method of drying water molecules quickly absorbs the energy and rapidly evaporates, which leads to high drying rate, decreased drying time, decreased energy consumption and better food quality (Doymaz et al., 2015; Kipcak, 2017).

In the literature several vegetables were dried using the microwave dring methods. Some of them are; green bean (Doymaz et al., 2015), green pea (Zielinska, Zapotoczny, Alves-Filho, Eikevik, Blaszczak, 2013), mushroom (Giri and Prasad, 2007), spinach (Alibas Ozkan et al., 2007). About the drying of asparagus only a few studies are made by the reaserchers. Drying characteristics of asparagus roots are studied using hot-air technique by Bala, Hoque, Hossain, and Borhan (2010), with the same drying method the color and rehydration abilities of wild asparagus are studied by Jokic et al. (2009). Nindo et al. (2003) studied the retention of physical quality and antioxidants in asparagus using microwave method but not studied the drying characteristics.

As it seen from the literature the microwave drying kinetics of asparagus was not studied. To contribute to the published literature, the microwave drying kintetics of culture and natural asparagus is studied using the microwave power levels of 90, 180 and 360 W. Moisture ratios were modelled using the four different drying models, furthermore effective moisture diffusivity values, activation energy values, color values and volumetric decrease values were calculated.

Material and methods

Samples

Culture asparagus were purchased in May 2017 from a local gross market in Istanbul, Turkey and natural asparagus were harvested from Keşan, Edirne Turkey (Thrace region). Both types of asparagus were kept in a refrigerator (Arcelik 1050; Arcelik, Eskisehir, Turkey) at a temperature of 4°C. Before the microwave drying experiments, similar sized ones were removed from the refrigerator (Figure 1a), and were left at room temperature in a desiccator for 2h. The initial parameters of the asparagus types are given in Table 1.

By using the AOAC method (Association of Official Analytical Chemists [AOAC], 1995) the initial moisture content of asparagus types determined as 9.59 and 6.76 kg water × kg dry matter^{-1} for culture and natural, respectively.

Drying experiments

Drying experiments were run on a 800 W maximum output working at 2450 MHz, Bosch HMT72G420 microwave oven (Robert Bosch Hausgerate GmbH, Munich, Germany). The drying procedure was carried out at microwave powers of 90, 180 and 360W. Drying was terminated when the moisture contents were decreased to 0.11 kg water × kg dry matter^{-1}. Then dried asparagus (Figure 1b) was cooled and stored in low-density polyethylene bags.

Table 1. Initial parameters of the culture and wild asparagus.

Asparagus type	Culture			Natural		
Power level (W)	90	180	360	90	180	360
Diameter (cm)	1.2 ± 0.1	1.1 ± 0.1	1.0 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1
Length (cm)	5.2 ± 0.2	5.0 ± 0.2	5.3 ± 0.2	6.0 ± 0.5	5.5 ± 0.5	6.5 ± 0.5
Weight (g)	7.74 ± 0.28	7.11 ± 0.25	6.10 ± 0.18	2.04 ± 0.14	1.99 ± 0.12	2.57 ± 0.19

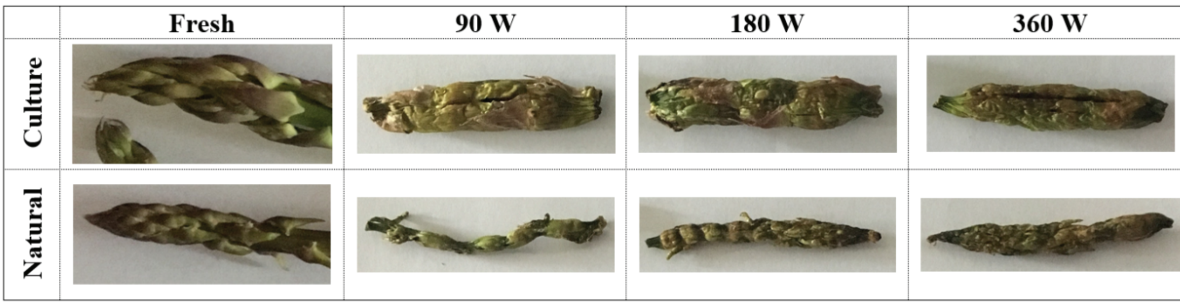

Figure 1. Pictures of the fresh and dried culture and natural asparagus.

All drying experiments were repeated three times, and the average moisture content values were used to plot the drying curves.

Mathematical modelling

Using the equations of (1), (2) and (3), the moisture content (*M*), drying rate (*DR*) and moisture ratio (*MR*) of were calculated using (Kipcak, 2017):

$$M = \frac{m_w}{m_d} \quad (1)$$

where M is the moisture content as kg water × kg dry matter^{-1}, m_w is the water content as g, m_d is the dry matter content as g.

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad (2)$$

where MR is the moisture ratio (dimensionless), M_t, M_e and M_i are the moisture content at selected time, at equilibrium and the initial value in kg water × kg dry matter^{-1}.

Several drying models were tested and the best four of them is given in this paper (Table 2).

Statistical Analysis

Statistical data analysis was done using the Statistica 8.0 computer programme (StatSoft Inc., Tulsa, USA). Model parameters were estimated using a non-linear regression procedure based on the Lavenberg-Marquardt algorithm. All models were evaluated using the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE). In the literature, higher R^2 values and lower χ^2 and RMSE values were accepted as better results (Alibas, 2012; Vega-Gálvez, Ayala-Aponte, Notte, De La Fuente, & Lemus-Mondaca, 2008; Kipcak, 2017). χ^2 and RMSE equations are given in (3) and (4), respectively:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (3)$$

where MR_{exp} and MR_{pre} represent experimental and predicted values of moisture ratios, respectively. N is the total number of experiments, and z is the number of constants in the model.

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right)^{1/2} \quad (4)$$

Determination of effective moisture diffusivity

For drying agricultural products with a falling rate period, Fick's second law of diffusion is used. A simple diffusion model based on Fick's second law of diffusion was considered for the evaluation of moisture transport, which is given by the following equation:

$$\frac{\partial M}{\partial t} = \frac{\partial}{\partial x}\left(De_{ff}\frac{\partial M}{\partial x}\right) \quad (5)$$

The initial and boundary conditions for cylindrical geometry can be written as follows (Evin, 2011):

Table 2. Models used in fitting the experimental data.

Model	Equation	Reference
Logarithmic	$MR= a \exp(-kt) + b$	Doymaz et al. (2015)
Aghbashlo et al.	$MR = \exp((-k_1 t)/(1+k_2 t))$	Aghbashlo, Kianmehr, Khani, and Ghasemi (2009)
Alibas	$MR= a \exp((-kt^n) + (bt))+g$	Alibas (2012)
Midilli et al.	$MR= a \exp(-kt^n) + bt$	Midilli, Kucuk, and Yapar (2002)

$$M = M_0; \quad t = 0; \quad 0 \le r \le R \tag{6}$$

$$\frac{\partial M}{\partial r} = 0; \quad t > 0; \quad r = 0 \tag{7}$$

$$M = M_e; \quad t > 0; \quad r = R \tag{8}$$

where M_o is the initial moisture content ($g_{water}/g_{dry\ matter}$), M_e is the equilibrium moisture content ($g_{water}/g_{dry\ matter}$), t is the drying time (min) and R is the cylinder radius (m). The analytical solution of Fick's second law for a finite cylinder with the assumptions of (i) uniform initial moisture distribution (ii) negligible shrinkage (iii) constant diffusion coefficients and temperature during the drying process is given in (9) (Whitaker & Young, 1972):

$$MR = \frac{8}{\pi^2}\left[\sum_{n=1}^{\infty}\frac{4}{a^2\alpha_n^2}\exp\frac{Ka^2\alpha_n^2 t}{\pi^2}\right]\left[\sum_{n=0}^{\infty}\frac{4}{(2n+1)^2}\exp\left[-K(2n+1)^2 t\left(\frac{a}{l}\right)^2\right]\right] \tag{9}$$

where a is taken as the radius of finite cylinder as m, l is the one-half length of cyclinder as m, K is the D_{eff} (Effective moisture diffusivity, $m^2\ s^{-1}$) × π × a^{-2}. The complex Eq. (9) can be simplified as (10);

$$MR = \frac{8}{\pi^2}\exp\left[-Kt\left(\frac{a}{l}\right)^2\right] \tag{10}$$

by taking the ln of both sides and putting the K value (10) D_{eff} can be calculated from the plot of *ln(MR)* versus *t*.

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \frac{D_{eff}\times\pi^2}{a^2}\times\left(\frac{a}{l}\right)^2\times t \tag{11}$$

Determination of activation energy

The dependence of the effective diffusivity Arrhenius equation on temperature is described by the Arrhenius equation (12) (Kipcak, 2017):

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

where D_0 ($m^2\ s^{-1}$), E_a (kJ mol^{-1}), R (kJ $molK^{-1}$) and T (°C) are the pre-exponential factor of Arrhenius equation, activation energy, universal gas constant and temperature, respectively. However, during the microwave drying processes, the temperature is not a directly measured variable. Thus, to calculate the activation energy, the equation of (13) can be used, which shows the relationship between the effective diffusivity and the microwave power level to a sample weight can be used (13) (Kipcak, 2017):

$$D_{eff} = D_0 \exp\left(-\frac{E_a\times m}{P}\right) \tag{13}$$

where *m* is the sample weight as kg and *P* is the microwave power (W).

Color measurement

Each asparagus sample was measured before and after drying was obtained using a Minolta Chroma Meter CR-400 (Konica Minolta Sensing Inc., Japan). The results for the colours were as follows: L-values (lightness/darkness), a-values (redness/greenness) and b-values (yellowness/blueness). The colorimeter was calibrated against a standard white and black plate in order to accurately determine the color parameters of the Hunter L* a* b* values. Color analysis was done on selected asparagus samples at five different locations and the average value was estimated. The colour of a product is an important attribute for quality assessment.

Determination of the volume decrease

Volume decrease represents the volume reduction or the change of selected dimensions occurring due to the moisture taken away from the sample structure in a drying process and can be calculated as given in (14) (Junqueira, Correa, & Ernesto, 2017):

$$Volume\ shrinkage = \left(\frac{V_i - V_t}{V_i}\right)\times 100 \tag{14}$$

where V_i and V_t are the volumes at the initial and at the time t, respectively.

Results and discussion

Drying curves

In Figure 2, the effect of different microwave power levels on the drying of culture and natural asparagus is given. The initial average moisture contents of culture and natural asparagus was 9.59 and 6.76 kg water × kg dry matter^{-1}, respectively and decreased to 0.11 kg water × kg dry matter^{-1} after drying process. The type of the plot is similar with the studies given in the literature (Doymaz et al., 2015; Zarein et al., 2015).

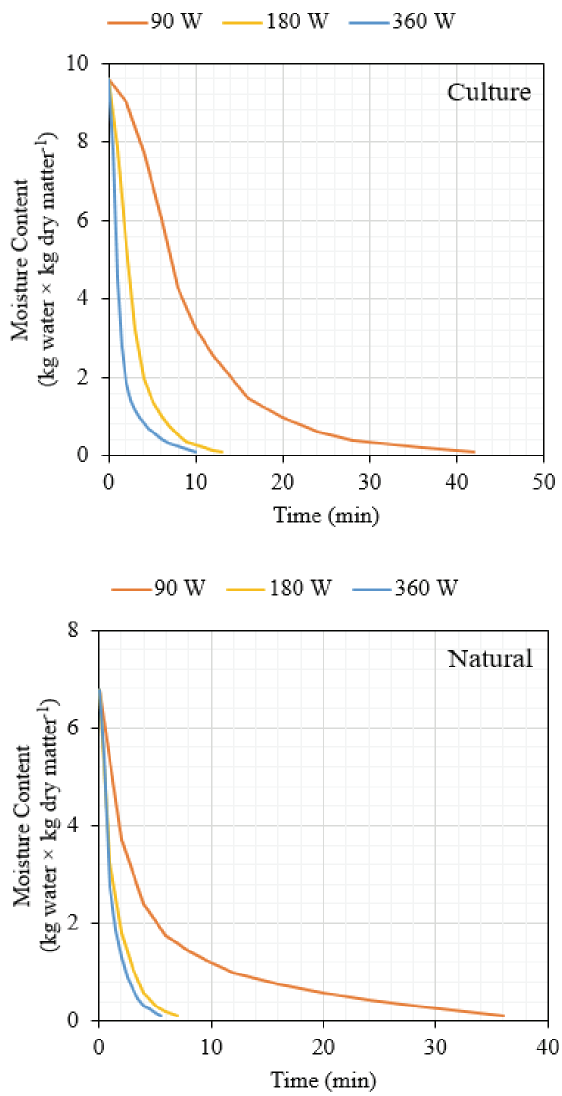

Figure 2. Drying curves of culture and natural asparagus at different MW power levels.

The increase in the microwave power level lead to the rapid dehydration thus decrease the drying times. The drying process time was found as 42, 13 and 10 min. for the microwave power level of 90, 180 and 360 W, respectively in the culture asparagus, on the other hand in the natural asparagus, the drying process time was found as 36, 7 and 5.5 min. for the microwave power level of 90, 180 and 360 W, respectively. As explained in the literature, higher heat absorption leads to higher product temperature, higher mass transfer driving force, faster drying rates and shorter drying times (Kipcak, 2017; Demirel & Ismail, 2017).

Mathematical modelling results and the evaluation of drying models

In the analysis of drying data, the MR kinetics is fundamental to explain the drying process of asparagus samples. Non-linear regression was used to obtain parameter values of each model. The values of coefficient of determination, root mean square error and reduced chi-square with estimated parameters for the four models are shown in Table 3.

The best model for describing the drying characteristics of culture and natural asparagus was chosen as the one with the highest R^2 values and the lowest χ^2 and RMSE values. As seen from the tables, R^2 values higher than 0.98 indicating a good fit since R^2 value close to unity implies that the predicted drying data is close to the experimental drying data. This means that all established models successfully described the relation between time and MR. Another statistical parameters calculated to compare the model's accuracy were χ^2 and RMSE values, which represent the differences between the predicted and experimental values.

Therefore, the fact that $\chi2$ and RMSE values are close to zero is desired. The statistical parameter estimations showed that R^2, χ^2 and RMSE values ranged from 0.9822 to 0.9999, 0.000014 to 0.002772 and 0.002633 to 0.04621, respectively. Of all the models tested, the Alibas model gave the highest R^2 value and the lowest χ^2 and RMSE values.

Effective moisture diffusivity values

From the plot of ln(MR) against drying time (s) obtained effective moisture diffusion equations are given in (15) through (20):

From the slope the values of D_{eff} are calculated as 3.78×10^{-07}, 1.17×10^{-06} and 1.54×10^{-06} m^2 s^{-1} for the microwave power levels of 90, 180 and 360W, respectively for the culture asparagus. Similarly for the natural asparagus, the values of D_{eff} are calculated as 4.58×10^{-07}, 1.93×10^{-06} and 4.10×10^{-06} m^2 s^{-1} for the microwave power levels of 90, 180 and 360W, respectively. Similar results were obtained on drying of sunflower seed (Darvishi et al., 2013). The values lie within the general range of 10^{-6} to 10^{-11} m^2 s^{-1} for food materials (Zarein, Samadi, & Ghobadian, 2015).

In Figure 3 the effect of microwave power level on the D_{eff} values are given (Equations 21 and 22) and observed as the D_{eff} values increased with increasing microwave power meaning that the increase in microwave power causes a rapid temperature rise of a food product, which, in turn, increases vapour pressure (Doymaz et al., 2015; Kipcak 2017).

$$\text{Culture} \rightarrow \quad 90W = \ln(MR) = -0.0019 \times t + 0.0672 \; (R^2 = 0.9936) \quad (15)$$

$$\text{Culture} \rightarrow \quad 180W = \ln(MR) = -0.0059 \times t - 0.0244 \; (R^2 = 0.9950) \quad (16)$$

$$\text{Culture} \rightarrow \quad 360W = \ln(MR) = -0.0069 \times t - 0.5427 \; (R^2 = 0.9495) \quad (17)$$

$$\text{Natural} \rightarrow \quad 90W = \ln(MR) = -0.0016 \times t - 0.8929 \; (R^2 = 0.9580) \quad (18)$$

$$\text{Natural} \rightarrow \quad 180W = \ln(MR) = -0.0097 \times t - 0.4528 \; (R^2 = 0.9981) \quad (19)$$

$$\text{Natural} \rightarrow \quad 360W = \ln(MR) = -0.0122 \times t - 0.4357 \; (R^2 = 0.9931) \quad (20)$$

$$\text{Culture} \rightarrow \quad D_{eff} = 4 \times 10^{-09} \times P + 2 \times 10^{-07} \; (R^2 = 0.8492) \quad (21)$$

$$\text{Natural} \rightarrow \quad D_{eff} = 1 \times 10^{-08} \times P - 6 \times 10^{-07} \; (R^2 = 0.9937) \quad (22)$$

Table 3. Statistical results of four models at different drying conditions.

Model	Sample	Power level (W)	R^2	χ^2	RMSE
Logarithmic	Culture	90	0.9822	0.002772	0.04621
		180	0.9886	0.001390	0.033038
		360	0.9864	0.001365	0.033305
	Natural	90	0.9848	0.001448	0.032949
		180	0.9987	0.000205	0.011318
		360	0.9938	0.002083	0.039519
Aghbashlo et al.	Culture	90	0.9841	0.002259	0.043711
		180	0.9902	0.001097	0.030656
		360	0.9823	0.001652	0.038022
	Natural	90	0.9973	0.000225	0.01369
		180	0.9994	0.000068	0.007138
		360	0.9826	0.002017	0.040991
Alibas	Culture	90	0.9984	0.000306	0.013721
		180	0.9985	0.000220	0.011881
		360	0.9926	0.000879	0.024577
	Natural	90	0.9985	0.000185	0.010379
		180	0.9994	0.000171	0.008016
		360	0.9919	0.001343	0.027984
Midilli et al.	Culture	90	0.9963	0.000649	0.021199
		180	0.9973	0.000360	0.016033
		360	0.9877	0.001341	0.031716
	Natural	90	0.9977	0.000245	0.012772
		180	0.9999	0.000014	0.002633
		360	0.9892	0.001565	0.032262

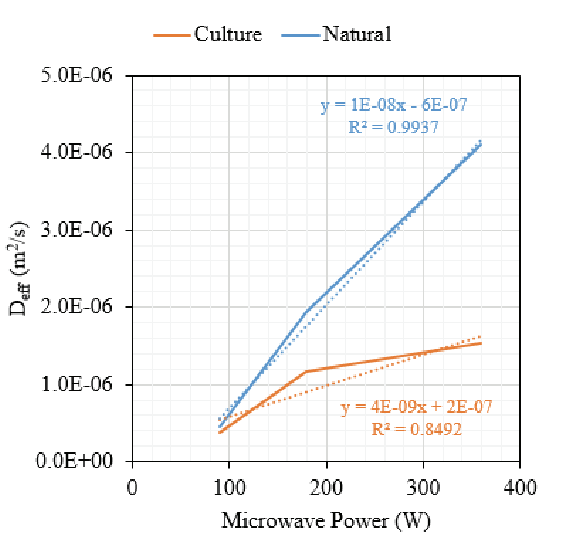

Figure 3. Plot of effective moisture diffusivity with respect to microwave power.

Activation energy values

In Figure 4, the plot of $\ln(D_{eff})$ against m/P is given for the culture and natural asparagus. From the slopes and intercepts of the plot E_a and D_0 can be calculated. Obtained Equations are given in (23) and (24):

Calculated values of D_0 and E_a are found as 2.38 × 10^{-06} m^2 s^{-1} and 20.967 kW/kg, respectively for culture asparagus and 1.21 × 10^{-05} m^2 s^{-1} and 146.020 kW/kg, respectively for natural asparagus. (Doymaz, 2013).

Color measurement

Table 4 shows the colour parameters L, a, and b values for dried culture and natural asparagus samples as a function of drying microwave power. The color values were measured as 42.03, 0.61, and 2.07 for "L", "a", and "b", respectively in the fresh culture asparagus, on the other hand in the natural asparagus, the color was measured as

45.89, -1.83, and 10.93 for “L”, “a”, and “b”, respectively. The microwave power level and drying time are the main factors affecting the color change of material during drying process. In comparison to the fresh asparagus, a significant rise in the L, a, and b values were observed ($p < 0.05$). Higher L values and lower a/b values are desirable in the dried products (Doymaz and Altıner, 2012).

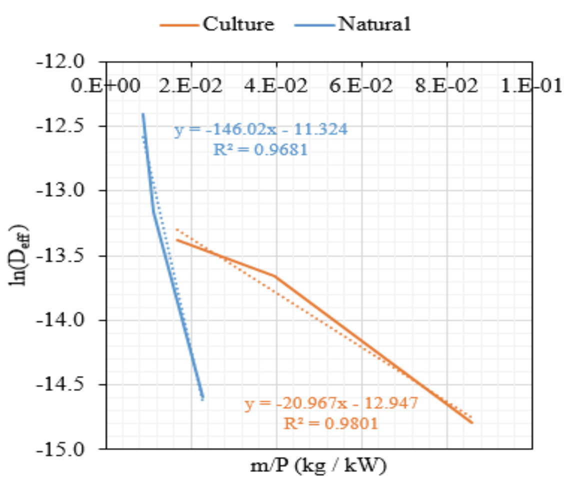

Figure 4. Plot of ln(D_{eff}) with respect to weigh per microwave power level.

As shown in Table 4, that the values of L, a and b parameter values for dried culture and natural asparagus samples increase with microwave power. Highest L values were obtained from samples dried at 90 W. To the contrary, the lightness values (8.34, 9.27, 12.34, and 21.51 at 90, 180, 360, and 600 W, respectively) decreased as microwave power level increased, The lightness values for culture asparagus (51.31, and 48.40, at 90 and 180 W, respectively) decreased as microwave power level increased. To the contrary, the lightness values for culture asparagus (48.40, and 50.25 at 180, and 360 W, respectively) increased as microwave power level increased. Also the values of a* parameter increased slightly with drying microwave power, which means that drying process preserves or enhances slightly the green colour of the culture and natural asparagus As with the case of lightness parameter, the value b is also influenced by the microwave drying power level. The b* values showed that all the dried samples were more yellow in colour. Microwave drying pushes liquid onto the surface and the liquid is usually converted into vapour. This process results in drying without causing surface overheating phenomena. Therefore, in terms of surface colour degradation, preservation of the product colour was good. a/b, which is a function of a and b values, was dependent on microwave power level. Of the all drying conditions used, the highest a/b values for culture and natur al asparagus was found with microwave drying at 180 W and the largest decrease in a/b value was found with microwave drying at 90 W.

Volume decrease

The volume decrease plot of the culture and natural asparagus are given in Figure 5. As it seen from the plot, time require to volume decrease the asparagus is decreased from increasing the microwave power level and natural asparagus decreased more rapidly than the culture asparagus. The average volume decrease values for culture and natural asparagus were obtained as 87.60 ± 0.38 % and 87.56 ± 0.51 %, respectively.

$$\text{Culture} \rightarrow \quad D_{eff} = 2.38 \times 10^{-06} \times \exp(-20.967 \times m \times P^{-1}) \; (R^2 = 0.9801) \tag{23}$$

$$\text{Natural} \rightarrow D_{eff} = 1.21 \times 10^{-05} \times \exp(-146.020 \times m \times P^{-1}) \; (R^2 = 0.9681) \tag{24}$$

Table 4. Color values of the fresh and dried culture and wild asparagus.

Sample	Power level (W)	*L*	*a*	*b*	*a/b*
Fresh culture	-	42.03±1.92	0.61±0.26	2.07±0.57	0.29
Fresh natural	-	45.89±1.75	-1.83±1.44	10.93±0.99	-0.16
Culture	90	51.31±2.77	0.98±0.41	18.19±1.14	0.05
	180	48.40±0.96	2.05±1.59	10.58±0.77	0.19
	360	50.25±2.65	0.73±0.58	9.93±1.88	0.07
Natural	90	54.16±3.15	-1.65±1.24	6.64±0.78	-0.25
	180	52.39±3.38	3.30±1.49	7.18±1.82	0.46
	360	46.21±1.23	0.69±0.28	10.06±1.56	0.07

Note. Means ± SD are given in the Table; significantly ($p < 0.05$).

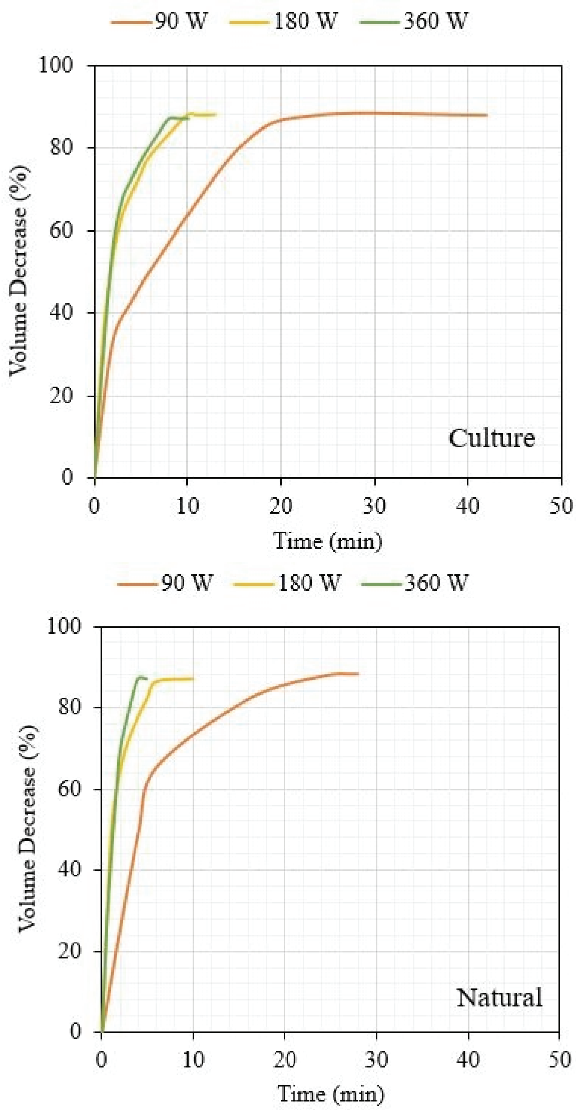

Figure 5. Volume decrease curves of culture and natural asparagus at different MW power levels.

Conclusion

In the present study, the drying characteristics of culture and natural asparagus were investigated in a microwave oven at different power levels. The drying times were decreased with increasing microwave power level and the drying process majorly took place at the falling-rate period. Alibas model gave the best statistical results. The effective moisture diffusivity values were changed between 3.78×10^{-07} and 1.54×10^{-06} m^2 s^{-1} for culture and 4.58×10^{-07} and 4.00×10^{-06} m^2 s^{-1} for natural asparagus. The activation energies were found as 20.967 kW kg^{-1} for culture and 146.020 kW kg^{-1} for natural asparagus. For the color analysis the best dried product were determined at the microwave power level of 90W and at all of the dried products for the increase in the microwave power level, the greenness values are decreased a little and yellowness and brightness values are increased. The average volume decrease values were found as 87.60 ± 0.38% and 87.56 ± 0.51% for culture and natural asparagus, respectively.

Conflict of interest: The authors declare that they have no conflict of interest.

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