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Investigation of Drying Kinetics of Zucchini using Microwave Energy

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Abstract

In this research work, drying characteristics of zucchini slices were investigated using a microwave conveyor dryer. The drying experiments with 5 mm, 10 mm, 15 mm thickness were carried out at 1.5 kW and 2.1 kW. The results showed that energy consumption and drying time decreased considerably with decreasing conveyor speed. Energy consumption was measured between 2.014-3.520 kWh. Particularly five empirical models were determined in defining the microwave drying behavior of zucchini slices by statistical analysis. The Page Model gave a better result for all drying experiments. The coefficients of the models were determined by non-linear regression analysis and the diffusion coefficient was calculated. The diffusion coefficients were found between 1.682×10^{-7}- 2.690×10^{-6} m^2/s. A color analysis was carried out to investigate the effects of microwave dryer on zucchini color quality. L* values at 2.1 kW and 0.210 m/min dried samples with 5 mm thickness were determined as the highest value.

Keywords: Conveyor, Color analysis, Modelling, Microwave drying, Zucchini

Mikrodalga Enerjisi Kullanarak Kabağın Kuruma Kinetiklerinin Araştırılması

Öz

Bu çalışmada mikrodalga konveyör kurutucu kullanarak kabak dilimlerinin kuruma davranışı araştırılmıştır. Kuruma deneyleri 5 mm, 10 mm ve 15 mm dilim kalınlıklarında, 1,5 kW ve 2,1 kW güçlerinde gerçekleştirildi. Elde edilen sonuçlara göre konveyör hızının azalması ile enerji tüketimi ve kuruma zamanı azalmıştır. Enerji tüketimi 2,014-3,520 kWh arasında ölçülmüştür. Kabak dilimlerinin istatiksel olarak kuruma davranışı beş deneysel model ile tanımlanmıştır. Tüm kuruma deney sonuçlarına göre Page model daha iyi sonuç vermiştir. Non-lineer regression analizi ile modeldeki katsayılar ve difüzyon katsayısı belirlendi. Difüzyon katsayıları $1,682 \times 10^{-7}$- $2,690 \times 10^{-6}$ m^2/s arasında hesaplandı. Mikrodalga kurutucunun kabağın renk kalitesindeki etkisi göre en yüksek L* değeri 5 mm dilim kalınlığında, 2,1 kW ve 0,210 m/dk konveyör hızında belirlenmiştir.

Anahtar kelimeler: Konveyör, Renk analiz, Modelleme, Mikrodalga kurutma, Kabak

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1. INTRODUCTION

Zucchini (Cucurbita pepo L.), green squash, has a similar shape like cucumber. It is usually marketed in fresh, being eaten raw in salads and served cooked in soups or in meals. Zucchini vegetables are important in most of the daily diets and can be used to alleviate most of the micronutrient deficiencies. However, zucchini vegetables are mostly available during the summer seasons. Therefore, it is necessary to preserve them in order to use it also during the winter season when they are in short supply. However, zucchini is a highly decayable vegetable that deteriorates rapidly after slicing. Its shelf life is 1–2 days [1, 2].

New methods are purposed at to decrease energy consumption and drying time as well as the quality of food. Microwave drying is one of the most interesting methods for drying materials. Microwave drying has considerable advantages, especially with take into consideration to energy efficiency. Since heat is transferred from the surface of food to the inside by convection and conduction in conventional drying methods, however, in this procedure, it may result in a temperature gradient between outside and inside the food. In addition, it implies higher energy input and relatively long drying time. On the other hand, in microwave drying, the heat is generated inside the food in a short time when microwave energy infiltrates through it.

Microwaves penetrate greater depth than other conventional dryers, and this characteristic coupled with volumetric heating can lead to rise of heating rate with short drying time; and also reduce to a minimum of temperature difference between the surface and inside of material [3]. In general, because of the heat losses at the surface, the interior part reaches a higher temperature level and dries first. Moisture inside is driven out to the surface with low pressure [4].

In this study, considering the time and energy consumption is a major problem in drying industry, zucchini slices were dried using a microwave conveyor belt, which is considered an alternative moreover beneficial to conventional methods. The effect of microwave energy on some drying characteristics (drying time, moisture content, effective diffusivity) of zucchini was investigated experimentally for microwave powers and conveyor belt speed in a microwave conveyor belt dryer. In previous studies, single magnetron was used in microwave driers. In our study 3 magnetrons are used in order to reduce time and energy consumption. Also, the suitability of some empirical models was also specified for drying simulation of zucchini slices. Furthermore, a color analysis was carried out to investigate the effects of microwave energy on color of food quality.

2. MATERIAL AND METHOD

2.1. Material

Zucchini (Cucurbita pepo L.) cv. (see Figure 1), about 15–20 cm length and 5–6 cm diameter was obtained from the store of a local market (Tekirdağ/TURKEY) where it was stored at 4^{o}C dryer. Experiments were performed in a microwave conveyor belt dryer we designed (see Figure 2). The microwave drying system was a shape with 500 mm x 400 mm x 3500 mm (width x height x depth). The microwave energy was generated by means of 3 magnetrons of 700 W each for a maximum of 2.1 kW at 2.45 GHz. During the drying process, the conveyor speed was to regulate and could be set at the potentiometer of control unit. The weight of the zucchini slices during the drying process was determined with a scale (Presica XB 620 M; Precisa Instruments AG, Dietikon, Switzerland) of ± 0.001 g precision. The energy consumed during drying was measured by an energy device (Enda, Turkey). The color values of zucchini were conducted by a Hunter Lab D25LT colorimeter (Hunter Associates Laboratory, Inc., Virginia, USA).

Figure 1. Zucchini samples used in the experiments

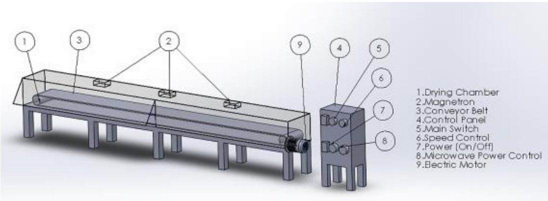


Figure 2. A schematic picture of microwave conveyor dryer

2.2. Drying Procedure

To determine the moisture content, the zucchinis were initially dried in an etuv at 105 °C (24 hours) and the dried mass was measured. The moisture content of the zucchinis with respect to the wet weight was 94±1%. Prior to the drying experiment, the zucchinis were cut into slices with thickness of 5 mm, 10 mm and 15 mm [5]. Then zucchini slices were placed on wooden bars. No pre-treatment was applied to the samples before the experiment carried out.

The drying could be controlled by the speed of conveyor belt and microwave power. Drying experiments were carried out for microwave powers of 1.5 kW and 2.1 kW, conveyor belt speed of 0.175 m/min, 0.210 m/min and 0.245 m/min respectively and applied for each thickness. Experiments were repeated three times for each test in order to minimize the uncertainties in the results. The development of the drying process was followed by weighting the bars containing zucchini in regular intervals of two minutes on a scale. The drying was completed when the moisture content reached a value of around 10±0.5% with respect to the wet weight. After each experiment, the energy consumption during drying and the color values of the dried zucchini were measured. In this study, the temperature factor which is important for drying, couldn't be measured due to the damage the microwave causes on the measurement instruments. Therefore, the effect of the microwave power was analysed.

2.3. Modeling of the Thin-Layer Drying

Due to the complexity of transport mechanisms, empirical models are often used to describe the thin-layer drying behavior of food materials. Of these models, those used frequently are given in Table 1 [6,7].

Table 1. Various mathematical models used ın modeling of drying

Model	Equation	Model	Equation
Newton	$MR = \exp(-kt)$	Geometric	$MR = at^{-n}$
Page	$MR = \exp(-kt^n)$	Wang and Singh	$MR = 1 + at + bt^2$
Henderson and Pabis	$MR = a\exp(-kt)$	Modified Page	$MR = \exp(-(kt)^n)$

The least squares method is commonly used to simulate the drying behavior, especially of biological material models presented up to now. In this method, the coefficients in the models are determined by minimizing the sum of the squared differences between the experimental and the theoretical moisture ratios. A better suitability between the model results and the empirical data is reached when the correlation coefficient (r) will be closer to 1 and the standard error (e_s) and the chi-square ($\chi 2$) will be closer to 0. These parameters are defined in Eq. (2-4) [8]. The moisture ratio (MR) in Table 1 is defined in Eq. (1) [9].

$$MR = m/mo \tag{1}$$

s

$$r = \frac{n_o \sum_{i=1}^{n_o} MR_{pre,i} MR_{\exp,i} - \sum_{i=1}^{n_o} MR_{pre,i} \sum_{i=1}^{n_o} MR_{\exp,i}}{\sqrt{n_o \sum_{i=1}^{n_o} (MR_{pre,i})^2 - \left(\sum_{i=1}^{n_o} MR_{pre,i}\right)^2} \sqrt{n_o \sum_{i=1}^{n_o} (MR_{\exp,i})^2 - \left(\sum_{i=1}^{n_o} MR_{\exp,i}\right)^2}} \tag{2}$$

$$e_s = \sqrt{\frac{\sum_{i=1}^{n_o} (MR_{pre,i} - MR_{\exp,i})^2}{n_o}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{n_o} (MR_{pre,i} - MR_{\exp,i})^2}{n_o - n_c} \tag{4}$$

where $MR_{\exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ is the ith predicted moisture ratio, n_c is the number of coefficients and n_o is the number of observations in the drying model.

2.4. Determination of Diffusion Coefficient

The approach at slopes was used to calculate for efficient humidity dispersal of zucchini slices in various drying situations. Lessening humidity capacity, drying features may transform in the drying phase. This can be checked by a dispersal structure [10], Here, zucchini slices were considered to be infinite plates, presented by Ficks' second law and the effective humidity dispersal (D_{eff}) within infinite plates can be concluded from the following Eq. (5). In case of symmetric boundary cases, neglecting the material reduction and with the assumption that water distribution in material to be equal, humidity rate can be regulated as Eq. (5) [11].

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}}{4L^2}t\right) \tag{5}$$

Dispersals are ruled by plotting preliminary drying data in terms logarithmic (MR) versus drying time t in the equation. The plot emerges a direct line with the slope as given Eq. 6.

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \tag{6}$$

Consequently, temperature is not absolutely quantitative inside the microwave drier, activation energy is found adjusted from the revised Arrhenius comparison. Besides, it is accepted related to impressive humidity dispersal and scale at microwave output power for sample weight (m/P) instead of air temperature as given Eq. (7) [12-14]:

$$D_{eff} = D_o.e^{-Ea.m/P} \tag{7}$$

2.5. Color Analysis

A color analysis provides information about the quality of the dried products. By means of the Spectrophotometer device, the L*, a*, b* color parameters of the zucchinis have been measured. The L* value represents the lightness, and it varies between 0 and 100. 0 represents blackness and 100 represents whiteness. a* value represents redness and greenness, and it varies between -90 and +90. b* represents blueness and yellowness, and varies between -90 and +90. Separated the L*, a* and b* coordinates, "C" value as the color density measurement derived from these values and the "H" value as the color tone measurement were calculated while comparing the colors of the zucchinis. The equations gained by means of the obtaining the C and H values have been presented in Eq. 8-12 [15, 16]:

$$\Delta L = L_{fresh} - L^* \tag{8}$$

$$\Delta a = a_{fresh} - a^* \tag{9}$$

$$\Delta b = b_{fresh} - b^* \tag{10}$$

$$C = \sqrt{a^{*2} + b^{*2}} \tag{11}$$

$$H = arctan\frac{b^*}{a^*} \tag{12}$$

3. RESULTS AND DISCUSSION

3.1 Modeling Drying Data

Curve fitting computations was carried out on the five drying models relating the drying time and moisture ratio. Additionally the drying curves based on the Page Model are illustrated along with the experimental moisture ratios in Figure 3-5. The results show that the most appropriate model in describing drying curves of zucchini is the Page Model with r in the range of 0.978–0.998, and with es in the range of $1.70\text{x}10^{-2}$–$5.8\text{x}10^{-2}$ and with ($\chi2$) in the range of $2.6\text{x}10^{-4}$–$3\text{x}10^{-3}$ for all of slices (see Table 2-10). It was determined that the most appropriate model is the Page Model in describing drying curves of zucchini for the experiments.

The Page Model is generally used in the food sector. Several research works have been presented in literature about the application of The Page model for foods. This is garlic sheets [17], Malaysian Canarium odontophyllum [18], rough rice [19], pistachios [20], apple [9], litchi [21], sweet cherrry [22], tomatoes [23], garlic [24].

Table 2. Analysis results of the models for 5 mm zucchini slices at different microwave power at conveyor belt speed of 0.175 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.015	0.938	0.142	0.020
	2100 W	k=0.018	0.891	0.172	0.030
Page	1500 W	$k=6x10^{-5}$ / n=2.406	0.997	0.017	0.0003
	2100 W	$k=9.1x10^{-6}$ /n=3.092	0.998	0.017	0.0003
Henderson and Pabis	1500 W	a=1.289 / k=0.021	0.911	0.102	0.010
	2100 W	a=1.317 / k=0.027	0.853	0.135	0.018
Geometric	1500 W	a=2.483 / n=0.418	0.651	0.199	0.040
	2100 W	a=2.327 / n=0.415	0.613	0.217	0.047
Wang and Singh	1500 W	a=-0.005/ b=0.000	0.974	0.057	0.003
	2100 W	a=-0.001/ b=0.000	0.983	0.045	0.002

Table 3. Analysis results of the models for 5 mm zucchini slices at different microwave power and conveyor belt speed of 0.210 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.019	0.962	0.128	0.016
	2100 W	k=0.020	0.895	0.181	0.033
Page	1500 W	k=0.0003/n=2.064	0.993	0.031	0.001
	2100 W	$k=9.1x10^{-6}$/n=3.143	0.995	0.028	0.001
Henderson and Pabis	1500 W	a=1.310 / k=0.025	0.944	0.085	0.007
	2100 W	a=1.345 / k=0.030	0.856	0.142	0.020
Geometric	1500 W	a=2.954 / n=0.519	0.707	0.193	0.037
	2100 W	a=2.569 / n=0.465	0.622	0.228	0.052
Wang and Singh	1500 W	a=-0.012/b=0.000	0.954	0.085	0.007
	2100 W	a=-0.002/b=0.000	0.970	0.064	0.004

Table 4. Analysis results of the models for 5 mm zucchini slices at different microwave power and conveyor belt speed of 0.245 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.012	0.909	0.147	0.022
	2100 W	k=0.016	0.928	0.106	0.011
Page	1500 W	k=0.000 / n=2.598	0.994	0.028	0.001
	2100 W	k=0.000 / n=1.996	0.982	0.040	0.002
Henderson and Pabis	1500 W	a=1.255 / k=0.016	0.879	0.117	0.014
	2100 W	a=1.172 / k=0.020	0.910	0.086	0.007
Geometric	1500 W	a=2.340 / n=0.375	0.602	0.210	0.044
	2100 W	a=1.809 / n=0.337	0.643	0.170	0.029
Wang and Singh	1500 W	a=-0.003/b=4 $x10^{-5}$	0.986	0.039	0.002
	2100 W	a=-0.006/b=9 $x10^{-5}$	0.998	0.013	0.0001

Table 5. Analysis results of the models for 10 mm zucchini slices at different microwave power and conveyor belt speed of 0.175 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.018	0.970	0.110	0.012
	2100 W	k=0.028	0.941	0.148	0.022
Page	1500 W	k=0.001 /n=1.904	0.998	0.016	0.00026
	2100 W	k=0.00029/n=2.301	0.981	0.056	0.003
Henderson and Pabis	1500 W	a=1.254 /k=0.023	0.952	0.073	0.005
	2100 W	a=1.375 /k=0.039	0.926	0.104	0.011
Geometric	1500 W	a=2.693 /n=0.479	0.717	0.176	0.031
	2100 W	a=3.235 /n=0.615	0.726	0.199	0.039
Wang and Singh	1500 W	a=-0.010/b=0.000	0.979	0.054	0.003
	2100 W	a=-0.019/b=0.000	0.923	0.117	0.014

Table 6. Analysis results of the models for 10 mm zucchini slices at different microwave power and conveyor belt speed of 0.210 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.019	0.946	0.143	0.021
	2100 W	k=0.021	0.934	0.160	0.026
Page	1500 W	k=0.00013/n=2.299	0.994	0.027	0.001
	2100 W	k=0.000066/n=2.569	0.996	0.024	0.001
Henderson and Pabis	1500 W	a=1.312 / k=0.026	0.920	0.102	0.010
	2100 W	a=1.345 / k=0.030	0.903	0.117	0.014
Geometric	1500 W	a=2.735 / n=0.484	0.675	0.202	0.041
	2100 W	a=2.800 / n=0.507	0.664	0.215	0.046
Wang and Singh	1500 W	a=-0.009 / b=0.000	0.958	0.077	0.006
	2100 W	a=-0.008/ b=0.000	0.954	0.083	0.007

Table 7. Analysis results of the models for 10 mm zucchini slices at different microwave power and conveyor belt speed of 0.245 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.016	0.961	0.109	0.012
	2100 W	k=0.020	0.974	0.102	0.010
Page	1500 W	k=0.0004/n=1.913	0.995	0.024	0.001
	2100 W	k=0.001 / n=1.818	0.998	0.015	0.0002
Henderson and Pabis	1500 W	a=1.229 / k=0.020	0.942	0.080	0.006
	2100 W	a=1.232 / k=0.025	0.958	0.068	0.005
Geometric	1500 W	a=2.622 / n=0.457	0.697	0.179	0.032
	2100 W	a=2.124 / n=0.426	0.692	0.183	0.033
Wang and Singh	1500 W	a=-0.009/b=0.000	0.982	0.046	0.002
	2100 W	a=-0.012/b=0.000	0.979	0.054	0.003

Table 8. Analysis results of the models for 15 mm zucchini slices at different microwave power and conveyor belt speed of 0.175 m/min

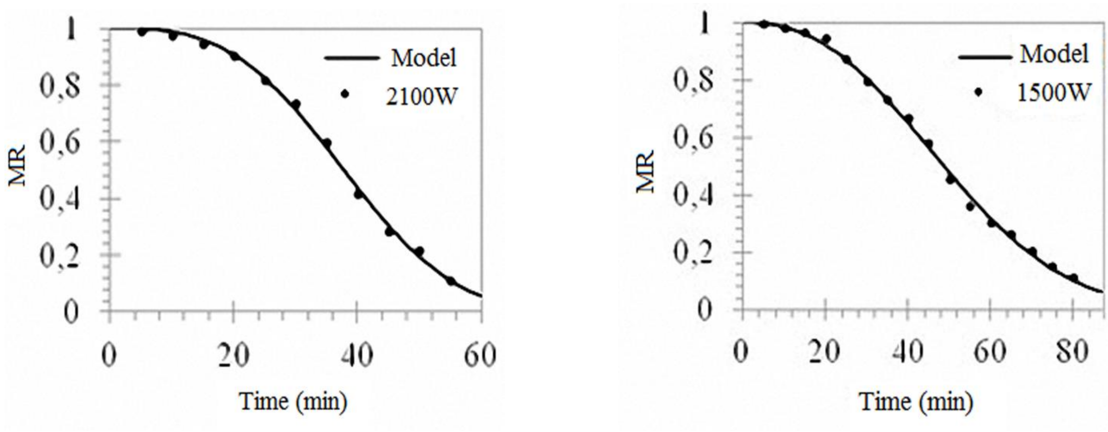
Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.017	0.929	0.160	0.026
	2100 W	k=0.020	0.921	0.175	0.031
Page	1500 W	k=0.000058/n=2.458	0.978	0.058	0.003
	2100 W	k=0.000035/n=2.723	0.987	0.045	0.002
Henderson and Pabis	1500 W	a=1.351 / k=0.024	0.906	0.116	0.013
	2100 W	a=1.369 / k=0.029	0.888	0.128	0.016
Geometric	1500 W	a=2.919 / n=0.495	0.655	0.221	0.049
	2100 W	a=2.792 / n=0.494	0.645	0.226	0.051
Wang and Singh	1500 W	a=-0.010/b=0.000	0.916	0.117	0.014
	2100 W	a=-0.007/b=0.000	0.935	0.100	0.010

Table 9. Analysis results of the models for 15 mm zucchini slices at different microwave power and conveyor belt speed of 0.210 m/min

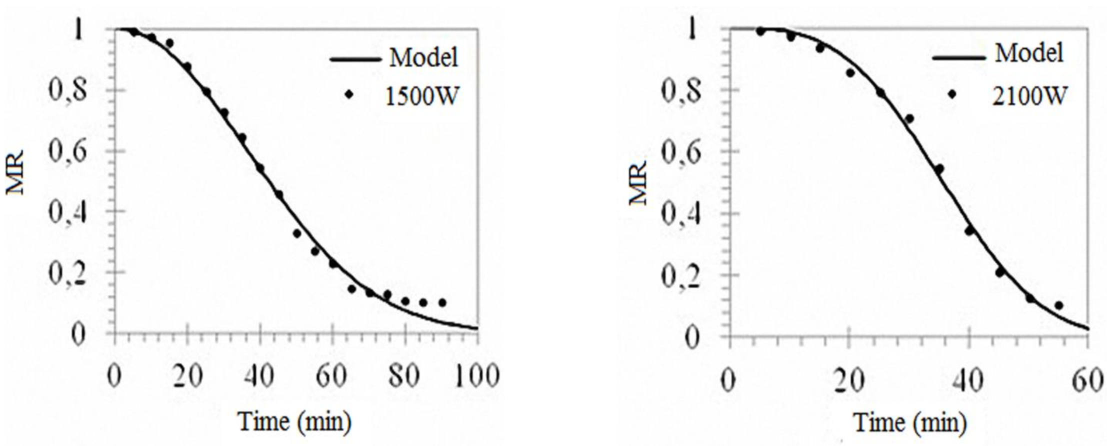
Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.018	0.943	0.148	0.022
	2100 W	k=0.021	0.914	0.169	0.029
Page	1500 W	k=0.000084/n=2.364	0.992	0.035	0.001
	2100 W	k=0.000035/n=2.786	0.993	0.030	0.001
Henderson and Pabis	1500 W	a=1.330 / k=0.024	0.920	0.106	0.011
	2100 W	a=1.340 / k=0.030	0.879	0.128	0.016
Geometric	1500 W	a=2.899 / n=0.498	0.667	0.213	0.045
	2100 W	a=2.599 / n=0.474	0.645	0.217	0.047
Wang and Singh	1500 W	a=-0.010 / b=0.000	0.941	0.096	0.009
	2100 W	a=-0.004/ b=0.000	0.966	0.068	0.005

Table 10. Analysis results of the models for 15 mm zucchini slices at different microwave power and conveyor belt speed of 0.245 m/min

Model	Microwave power	Constants	r	e_s	χ^2
Newton	1500 W	k=0.017	0.958	0.118	0.014
	2100 W	k=0.017	0.940	0.136	0.018
Page	1500 W	k=0.00043/n=1.893	0.980	0.053	0.003
	2100 W	k=0.0001 / n=2.312	0.997	0.019	0.00037
Henderson and Pabis	1500 W	a=1.309 /k=0.022	0.952	0.077	0.006
	2100 W	a=1.267 /k=0.023	0.914	0.098	0.010
Geometric	1500 W	a=3.136 /n=0.529	0.716	0.190	0.036
	2100 W	a=2.007 /n=0.373	0.623	0.202	0.041
Wang and Singh	1500 W	a=-0.013/b=0.000	0.955	0.096	0.009
	2100 W	a=-0.006/b=0.000	0.973	0.057	0.003



(a)



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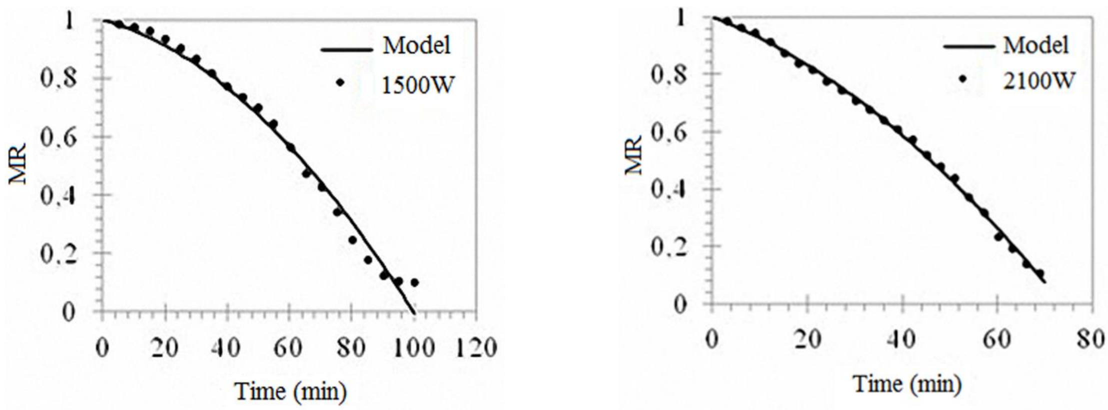

(c)

Figure 3. Drying Curves of 5 mm thick zucchini slices based on the proposed model for (a) conveyor speed of 0.175 m/min (b) Conveyor speed of 0.210 m/min (c) Conveyor speed of 0.245 m/min

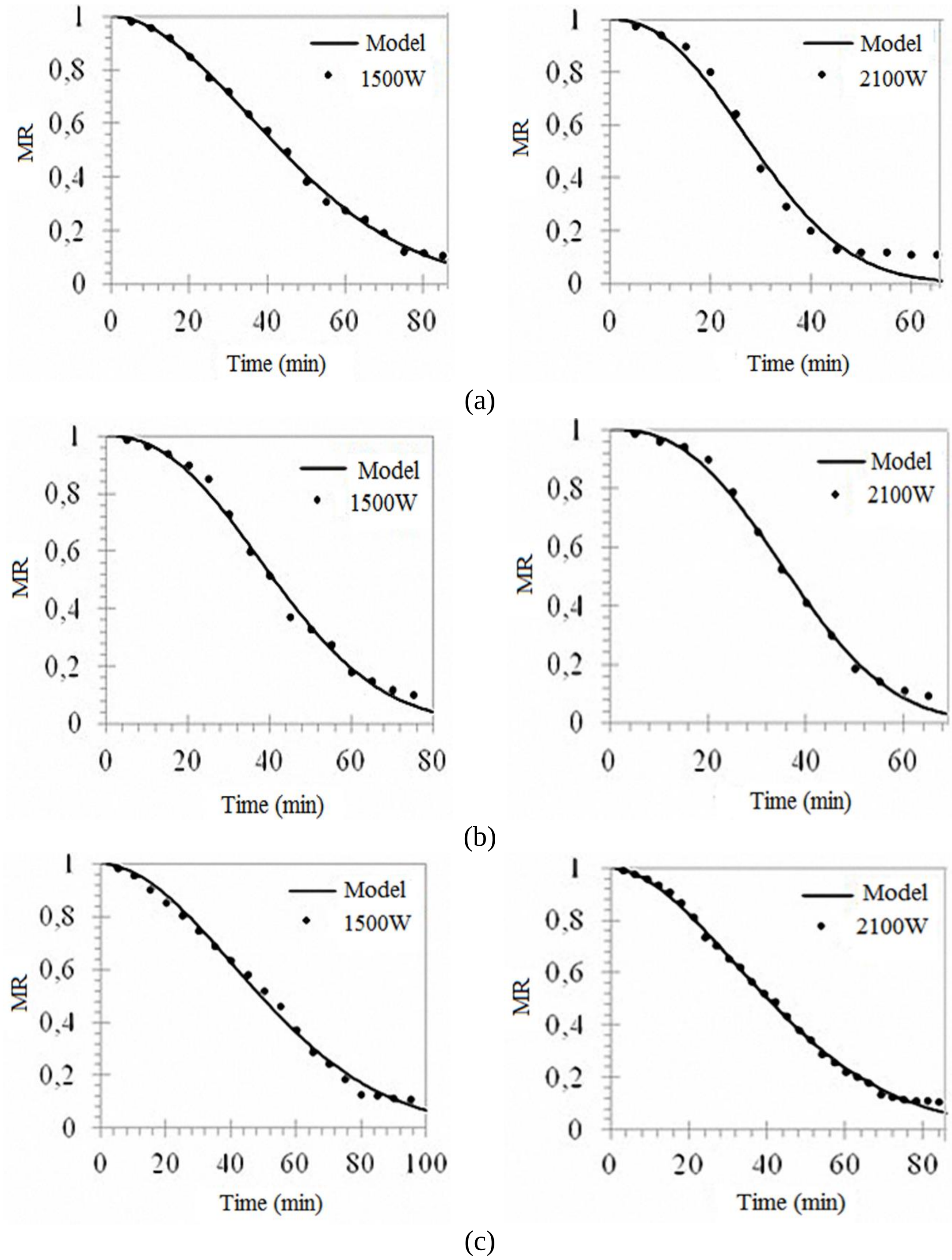

Figure 4. Drying Curves of 10 mm thick zucchini slices based on the proposed model for (a) Conveyor speed of 0.175 m/min (b) Conveyor speed of 0.210 m/min (c) Conveyor speed of 0.245 m/min

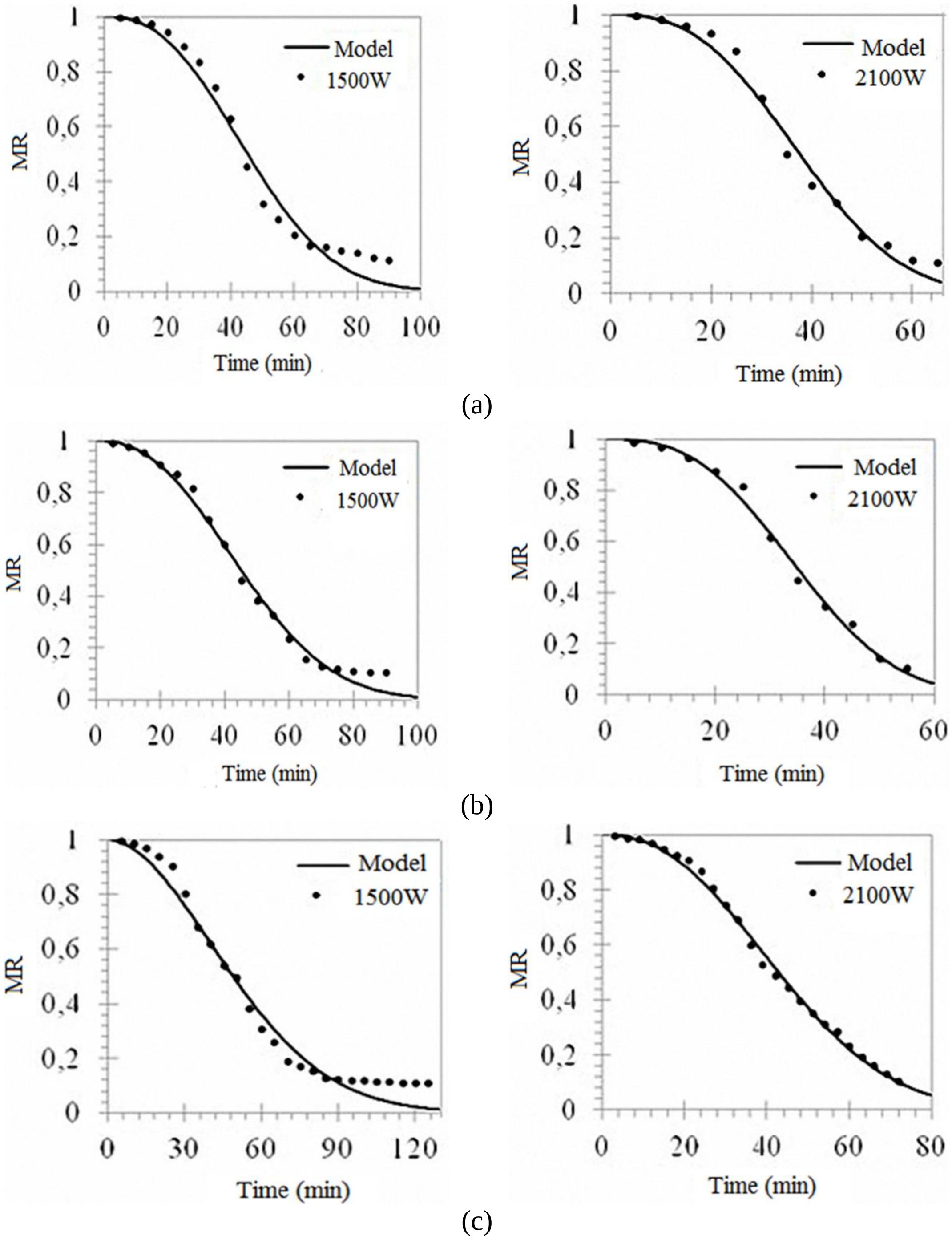

Figure 5. Drying Curves of 15 mm thick zucchini slices based on the proposed model for (a) Conveyor speed of 0.175 m/min (b) Conveyor speed of 0.210 m/min (c) Conveyor speed of 0.245 m/min

The results of former researchers have shown that internal mass transfer resistance controls the drying time due to presence of a falling drying rate period [25]. Therefore, the values of effective diffusivity (D_{eff}) at different output powers could be obtained by using Eq. (5). The moisture diffusivities of zucchini slices increased from $1.682x10^{-7}$ to $2.690x10^{-6}$ m^2/s in accordance with the increase of microwave output power from 1.5 kW to 2.1 kW for different amount of samples. The values ranged from $1.682x10^{-7}$ to $2.690x10^{-6}$ at 1.5 kW and 2.1 kW for each slice thickness of 5 mm, 10 mm and 15 mm. It can be seen that the values of Deff increased with increasing microwave power. This might be explained by the increased heating energy. which would increase the activity of the water molecules leading to higher moisture diffusivity when samples were dried at higher microwave power [25]. It is reported that the effective diffusion coefficients were changed in the range of $1.65x10^{-8}$-11.05×10^{-8} m^2/s for zucchini by [5].

The color change was measured and expressed as the L*. a* and b* . In accordance with the increase of the microwave power and belt speed, zucchini slices got higher L* value and higher b* value. Drying methods have a considerable effect on the color changes of zucchini slices. L* values of zucchini slices decreased during the drying [26]. L* values at 2.1 kW dried samples were the highest among the other dried samples which were closer to the L* values of fresh sample ($P < 0.05$). Dried zucchini slices at 1.5 kW had significantly darker color according to dried samples at 2.1 kW. This may be due to the low microwave power and long drying time.

Higher L* values are desirable in the dried products [27]. b* values of fresh samples were lower than the dried samples. a* values of fresh slices were lower than the other dried samples which showed a greener color. Dried samples of 15 mm at 2.1 kW and 0.175 m/min had the highest a*. The color criteria for zucchini slices under test conditions of 2.1 kW. 0.210 m/min and slice thickness of 5mm found the most appropriate use. Similarly [2] reported 65.26 of L*. 2.365 of a*. 36.73 of b* for slices of dried zucchini.

By the means of counter in the control panel, energy consumption was recorded during start and finish of drying in the microwave. As the microwave power decreases, the energy consumption increases. The reason of that is; as less heat is generated in the low microwave power, more time is required for the transfer of the heat from the product to the environment. Thus, time required for the water in the product to reach the evaporation temperature is prolonged and the energy spent for the evaporation is reduced. This prevents the achievement of efficient drying. Likewise, when drying times are considered, the time in the high microwave power is shortened and the time in the low microwave power is prolonged. If a comparison is made in terms of effect of conveyor belt speed on the drying period; it is measured that drying time increases in high conveyor belt speed and decreases in low conveyor belt speed. The reason of time disparity is; the intensity of the microwave energy in the oven is at a high value and that it is disposed to the energy less by swiftly passing from the zones where the microwave energy is intense at high conveyor belt speed. Consequently, the lowest energy consumption value for 5mm slice thickness is 0.175 m/min and 2.1 kW. It is believed that low energy consumption and short drying time will maket his drying system useful for not only in the food industry but in all of the industrial areas (heating, drying, chemistry etc.) as well. In this study, the possibility of solving the time and energy consumption problem by microwave belt systems is proved.

4. CONCLUSIONS

The concluding observations are as follows:

1- The most suitable model in describing drying curves of zucchini slices is the Page model for microwave conveyor drying.

2- The lowest energy consumption were measured as 2.014 kWh for 2.1 kW power level. 0.175 conveyor speed and 5 mm layer thickness. When the drying microwave power decreased, drying time and energy consumption have increased.

3- The diffusion coefficient for drying at 1.5 kW and 2.1 kW ranged from $1.682 x 10^{-7}$ to $2.690 x 10^{-6}$ m^2/s. The effective diffusivity increases with decreasing microwave power. Microwave power dependence of the diffusion coefficients was described by Arrhenius-type relationship.

4- Color analysis is important for foods epecially holding the quality for the production and for the commerce. From the results of color quality the color criteria was most appropriate to those of zucchini slices obtained at 2.1 kW and 0.210 m/min for slice thickness of 5 mm.

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