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Mathematical modeling of thin-layer microwave drying of corn husk and investigation of powder properties

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The aim of this study is to investigate the effect of different microwave powers on the drying kinetics of chopped corn husks and to determine the properties of the corn husk powder obtained after grinding the dried product. The drying behavior of corn husks was determined using eleven commonly used thin-layer models. The obtained powders were analyzed for moisture content, water activity, color, tapped and bulk densities, wettability, flowability, and cohesiveness. In addition, the effective moisture diffusivity and activation energy of corn husks were calculated from drying data. From the analysis of the results, the drying rate and the drying time of corn husk slices considerably decreased with increasing microwave power. Among all used drying models, the Page model was found to satisfactorily describe the kinetics of microwave drying of corn husk. The effective moisture diffusivity values ranged from 2.264×10^{-10} to 8.941×10^{-10} m^2s^{-1}.

Keywords: corn husk; microwave drying; agricultural waste; modeling; activation energy.

INTRODUCTION

Corn is one of the main agricultural products all over the world. Corn husks consist of thin cellulose-rich leafy sheets that cover the corn cob. Corn husks are an important by-product of the corn processing industry and have been either used as animal food or are returned to the harvested field. On the average, the husks contain 382 g cellulose, 445 g hemicellulose, 66 g lignin, 19 g protein, and 28 g ash per kg of dry matter [1]. Utilization of corn husks may potentially reduce environmental pollution and provide further profits to the farmers [2].

The main aim of drying which is one of the oldest food preservation techniques is to allow longer periods of storage, minimize packaging requirements, and transportation costs [3]. Drying can be accomplished using many techniques, e.g., microwave drying. In a microwave drying system, the microwave energy has an internal heat generative capacity and can easily penetrate the interior layers to directly absorb the moisture in the sample. The quick energy absorption causes rapid evaporation of water. Theoretically, microwave drying technique can reduce the drying time period [4]. In fact, the dehydration kinetics is important for the design and optimization of the drying process [5]. During drying, the determination of the rate of water removal and the effect of drying conditions on this rate is important and expressed in terms of drying models. Thin-layer drying equations which are practical, provide sufficiently good results and are important in mathematical modeling of drying [6]. Thin-layer drying is the process of drying in one layer of sample particles or slices.

Corn is one of the leading harvested crops in the world and corn husks constitute a large amount. Proper methods of treatment of husks will reduce the environmental pollution and at the same time, valuable nutrient sources in the husks will be saved. Considering the possible treatment methods, drying is the most suitable one. By drying, the stability of husks against chemical and biological decomposition will be increased and the amounts of waste material will be decreased. Although electrical methods, such as microwave drying, are considered to be expensive applications in waste treatment, high drying rates and feasibility of the drying systems for designs and different scales promote their use in future applications. According to the literature, corn husks were used as a substrate for fermentation of bioethanol and citric acid. Since the fermentation systems are to be well controlled for substrate composition and quality, use of dried materials will be more advantageous in those systems. In addition, there are few studies on the determination of the effective moisture diffusivity of the microwave drying process. The aims of this study are to observe the effects of different microwave powers on the drying kinetics of corn husks, to fit the experimental data to thin-layer drying models to estimate the model parameters and finally to determine the powder properties of corn husks.

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EXPERIMENTAL DETAILS

Materials

Fresh corns were obtained from a local supermarket in Izmir, Turkey. The husks were removed, washed, sorted, and sliced into a thickness of 0.48±0.02 mm.

Microwave drying

Experiments were performed in a domestic microwave oven (Arçelik MD 595, Turkey) at 2450 MHz with a maximum output power of 900W. Ten grams of sample was taken and placed in the oven. Drying experiments were performed at five different microwave powers (180, 360, 540, 720, and 900 W). For determination of the moisture loss, the samples together with the tray were taken out at uniform intervals and weighed using a digital balance with 0.01 g precision (Ohaus AR2140, USA). Drying process was ended when constant weight was recorded. The powder was obtained by grinding the dried material in a home type blender (Tefal Smart, MB450141, Turkey).

Mathematical modeling of drying data

The moisture ratio values (MR) were calculated using the obtained moisture content values from drying experiments for all microwave powers. The dimensionless moisture ratio can be calculated using the equation (1);

$$MR=\frac{M_t-M_e}{M_0-M_e} \quad (1)$$

Where M_t, M_0, and M_e are the moisture contents at any time, initial, and equilibrium (kg water/ kg dry matter), respectively.

Drying data were fitted to eleven (Lewis, Page, Modified Page I, Henderson and Pabis, Modified Henderson and Pabis, Logarithmic, Midilli, Modified Midilli, Two-term, Two-term Exponential, and Wang and Singh) well-known thin layer drying models. Nonlinear regression analysis was used to evaluate the parameters of the selected model using statistical software SPSS 16.0 (SPSS Inc., Chicago, IL, USA). The goodness of fit was determined using the coefficient of determination (R^2), the root mean square error (RMSE), and the reduced chi-square (χ^2). The high values of the coefficient of determination (R^2), the low values of the root mean square error (RMSE) and the reduced chi-square (χ^2) were chosen for the goodness of fit [6]. The effective moisture diffusivity was calculated by using Eq. 2 [7]:

$$MR=\frac{M_t-M_e}{M_0-M_e}=\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2D_{eff}}{4L^2}t\right) \quad (2)$$

where D_{eff} is the effective moisture diffusivity and L is the thickness of corn slices. For long drying times only the first term (n=1) of the series can be used, so the Eq. (3) can be written as:

$$MR=\frac{M_t-M_e}{M_0-M_e}=\frac{8}{\pi^2}\exp\left(-\frac{\pi^2D_{eff}}{4L^2}t\right) \quad (3)$$

Eq. (3) could be simplified to a straight-line equation as Eq. (4) [3,7, 8];

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

Physical analysis and analysis of powder properties

The moisture content of fresh corn husks and microwave dried corn husk powders was determined according to AOAC [9]. Water activity was measured using Testo-AG 400, Germany water activity measurement device. The color values of corn husks (L*, a* and b* values) were measured with a Minolta CR-400 Colorimeter, Japan. Total color change (ΔE) of microwave dried corn husks with respect to fresh corn husks was calculated by using Eq. 5;

$$\Delta E=\sqrt{\Delta L^2+\Delta a^2+\Delta b^2} \quad (5)$$

For the determination of tapped and bulk densities, flowability and cohesiveness the methods of Jinapong *et al*. [10] were used. The average wettability time of microwave dried corn husk powders was determined using the method of Goula and Adamopoulos [11].

Data were analyzed using statistical software SPSS 16.0 (SPSS Inc., Chicago, IL, USA). The data were also subjected to analysis of variance (ANOVA) and Duncan's multiple range test (α=0.05) to determine the difference between means. The drying experiments were replicated twice and all analyses were triplicated.

RESULTS AND DISCUSSION

Results of Physical Analysis

The moisture contents and color values (L*, a*, and b*) of fresh corn husks were found to be 76.95±5.07% (wet basis, wb), and 73.58±1.33, -3.97±0.46, and 18.73±1.79, respectively. The results of the physical analyses applied to corn husk powder and the total color change are given in Table 1.

Table 1. Results of the physical analyses applied to microwave dried corn husk powders.

Properties	Microwave Power (Watt)				
	180	360	540	720	900
Moisture Content (%, wb)	11.53±0.20[b]	7.59±1.87[a]	7.12±0.37[a]	5.96±0.31[a]	6.52±0.68[a]
Water Activity	0.40±0.03[b]	0.38±0.02[b]	0.30±0.02[a]	0.29±0.04[a]	0.26±0.01[a]
ΔE	9.92±0.13[b]	8.68±0.36[a]	8.30±0.70[a]	10.80±0.29[c]	9.55±0.31[b]

[a-c] Different letters in the same row indicate a significant difference between averages at $P<0.05$.

The results showed that the microwave drying process removed about 90% of the water from fresh corn husks at microwave powers between 360W-900W. Moisture contents and water activity values of microwave dried corn husk powder decreased according to increasing microwave power due to a high transfer rate at high microwave power. However, an increase in microwave power from 720W to 900W caused a slight increase in the moisture content due to structural changes. The decrease in moisture content was not found statistically significant for microwave powers between 360 and 900 W ($P>0.05$). The water activity values of corn husks are within acceptable limits for safe storage of products. The lowest color change was observed from the drying experiment at 540W. Chua and Chou [12] studied the color change in carrots at microwave powers of 100, 300, and 500 W and determined the lowest color change at 500 W microwave power. In a study by Ozkan *et al*. [13], it was reported that considering the color change of microwave dried (90-1000W) spinach at energy levels of 500, 650, and 700W, the measured color values were very close to those of the fresh spinach. The result of this study is consistent with the studies of Chua and Chou [12] and Ozkan *et al*. [13].

Effect of different microwave powers on the drying kinetics of corn husks

The drying behavior of corn husks was determined from the mass loss in the samples of known initial moisture content (76.95±5.07% (wb)). As expected, drying time of corn husk samples decreased with increasing microwave power, and so it was observed that drying time of the samples at 540W was less than half of the drying time at 180W. The drying rates were calculated (kg water/kg dry matter.min) and plotted against the moisture ratio (kg water/kg dry matter) for drying of corn husk slices as shown in Fig. 1. The drying rates increased with the increase in microwave output powder and the highest values of the drying rate were obtained during the experiment at 900W. Constant drying rate periods ranged between 1.13 and 1.85 kg water/ (kg dry matter.min)$^{-1}$ for microwave powers between 180 and 900 W, respectively. Constant rate period was followed by a falling rate period for all microwave powers.

In order to describe the drying kinetics of corn husks, eleven different semi-empirical models were fitted to experimental data and the summary of model parameters of thin-layer drying models, as well as the statistical results (R^2, RMSE, and χ^2) are presented in Table 2. It was reported that the most suitable thin-layer drying model is that which provides the highest R^2 value and the lowest RMSE and χ^2 values [14]. In this study, the coefficient of correlation (R^2) was one of the primary criteria for selecting the best model to define the microwave drying behavior of corn husk slices. Calculated R^2 values were found to be 0.999 for Page, Modified Henderson and Pabis and Two-term Exponential models.

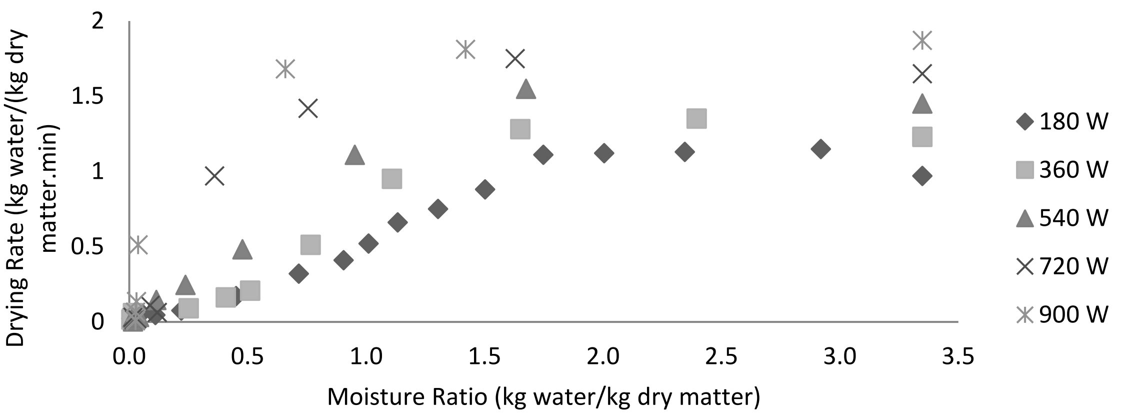

Fig. 1. Variation of the drying rate (kg water / (kg dry matter min^{-1}) as a function of the moisture ratio (kg water/kg dry matter) for different microwave powers.

Table 2. Coefficients of the model equations obtained from the statistical analysis of drying data.

Model	*P*(W)	Model Constants						R^2	χ^2	RMSE
Lewis	180	k=0.448						0.997	2.819E-04	0.01636
$(MR = e^{-kt})$	360	k=0.845						0.996	4.217E-04	0.01966
	540	k=1.335						0.999	8.449E-05	0.00872
	720	k=1.394						0.999	8.720E-03	0.00320
	900	k=2.009						0.999	4.839E-05	0.00651
Page	180	k=0.406	n=1.095					0.999	9.457E-05	0.00948
$(\mathrm{MR} = \mathrm{e}^{-\mathrm{k}(\mathrm{t})^{\mathrm{n}}})$	360	k=0.794	n=1.159					0.999	1.619E-05	0.00385
	540	k=1.335	n=0.985					0.999	8.182E-05	0.00858
	720	k=1.697	n=1.002					0.999	1.143E-05	0.00319
	900	k=2.069	n=1.084					0.999	6.021E-06	0.00230
Modified Page I	180	k=4.176	n=0.107					0.997	2.823E-04	0.01638
$(MR = e^{(-kt)^n})$	360	k=0.967	n=0.874					0.996	4.216E-04	0.01966
	540	k=1.134	n=0.996					0.999	8.450E-05	0.00872
	720	k=0.963	n=1.148					0.999	2.691E-03	0.04891
	900	k=1.489	n=1.349					0.999	4.838E-05	0.00651
Henderson and Pabis	180	k=0.459	a=1.027					0.998	2.151E-04	0.01429
$(MR = ae^{-kt})$	360	k=0.863	a=1.023					0.997	3.599E-04	0.01816
	540	k=1.332	a=0.997					0.999	8.357E-05	0.00867
	720	k=1.395	a=1.000					0.999	1.152E-05	0.00320
	900	k=2.013	a=1.002					0.999	4.773E-05	0.00646
Modified Henderson and Pabis	180	a=1.084	b=-0.042	c=-0.042	k=0.435	g=42.097	h=0.084	0.999	5.415E-05	0.00717
$(MR = ae^{-kt} + be^{-gt} + ce^{-ht})$	360	a=-1.588	b=-1.588	c=4.187	k=0.548	g=0.549	h=0.608	0.999	1.223E-04	0.01059
	540	a=7.647	b=7.426	c=-14.077	k=1.106	g=1.133	h=1.106	0.999	7.950E-05	0.00846
	720	a=-0.774	b=0.790	c=0.978	k=0.144	g=0.153	h=1.423	0.999	7.693E-06	0.00262
	900	a=-3.737	b=2.369	c=2.369	k=1.490	g=1.582	h=1.583	0.999	1.089E-05	0.00309
Logarithmic	180	k=0.427	a=1.040	c=-0.024				0.999	9.336E-05	0.00942
$(MR = ae^{-kt} + c)$	360	k=0.804	a=1.040	c=-0.024				0.998	1.987E-04	0.01350
	540	k=1.307	a=1.001	c=-0.006				0.999	7.000E-05	0.00794
	720	k=1.002	a=1.384	c=-0.002				0.999	9.422E-06	0.00289
	900	k=1.979	a=1.007	c=-0.005				0.999	3.237E-05	0.00532
Midilli	180	k=0.440	a=1.018	b=-0.002				0.999	1.114E-04	0.01029
$(MR = ae^{-kt} + bt)$	360	k=0.832	a=1.018	b=-0.004				0.998	2.355E-04	0.01469
	540	k=1.319	a=0.996	b=-0.002				0.999	7.198E-05	0.00805
	720	k=1.388	a=1.000	b=0.000				0.999	1.235E-05	0.00331
	900	k=2.001	a=1.002	b=-0.001				0.999	3.960E-05	0.00589
Modified Midilli	180	k=0.431	b=-0.003					0.999	1.348E-04	0.01132
$(MR = e^{-kt} + bt)$	360	k=0.816	b=-0.004					0.997	2.671E-04	0.01565
	540	k=1.324	b=-0.001					0.999	7.292E-05	0.00810
	720	k=1.389	b=0.000					0.999	1.209E-05	0.00328
	900	k=1.998	b=-0.001					0.999	4.016E-05	0.00593
Two Term	180	k_1=0.459	k_2=-0.459	a=0.545	b=0.482			0.998	2.151E-04	0.01429
$(MR = ae^{-k_1 t} + be^{-k_2 t})$	360	k_1=0.863	k_2=0.863	a=0.516	b=0.508			0.999	3.600E-04	0.01816
	540	k_1=1.332	k_2=1.332	a=0.396	b=0.601			0.999	8.357E-05	0.00867
	720	k_1=1.395	k_2=1.395	a=0.318	b=0.682			0.999	1.152E-05	0.00320
	900	k_1=2.013	k_2=2.013	a=0.507	b=0.495			0.999	4.773E-05	0.00646
Two Term Exponential	180	k=0.547	a=1.561					0.999	1.005E-04	0.00977
$(MR = ae^{-kt} + (1-a)e^{-kat})$	360	k=1.100	a=1.681					0.999	1.677E-05	0.00392
	540	k=1.355	a=1.127					0.999	8.439E-05	0.00872
	720	k=1.421	a=1.147					0.999	1.136E-05	0.00318
	900	k=2.382	a=1.519					0.999	5.973E-06	0.00229
Wangh and Singh	180	a=-0.289	b=0.020					0.968	3.060E-03	0.05392
$(MR = 1 + at + bt^2)$	360	a=-0.521	b=0.065					0.965	3.727E-03	0.05845
	540	a=-0.692	b=0.110					0.904	1.007E-02	0.09519
	720	a=-0.755	b=0.132					0.920	8.923E-03	0.08906
	900	a=-0.928	b=0.193					0.882	1.435E-02	0.11204

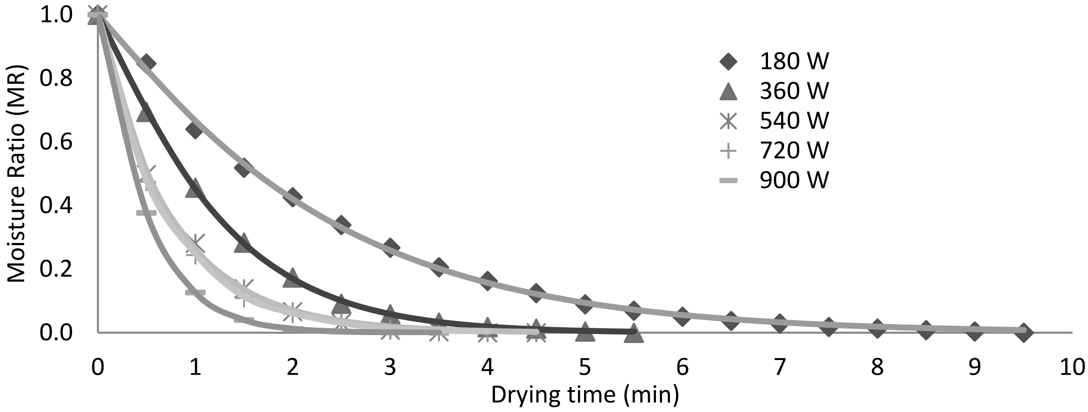

Fig. 2. Experimental and predicted moisture ratio values obtained by the Page model.

As a result of statistical analysis, the Page model was found to be the most appropriate one with a higher value of the coefficient of determination (R^2) and lower reduced chi-square (χ^2) and root mean square error (RMSE). The Page model represents a non-linear relationship between ln (MR) and drying time. The experimental and predicted moisture ratio values obtained using the Page model are given in Fig. 2. In addition, Arabhosseini *et al*. [15] reported that small numbers of the model parameters are preferable to find a relationship between the parameter values and the drying conditions, which is valid for the Page model. Several researchers reported that the Page model was chosen to determine the hot air drying behavior of black tea [8], microwave vacuum and hot air drying behavior of mint [3], microwave drying behavior of *Pandanus amaryllfolius* leaves [16], microwave drying behavior of spinach [13], hot air drying behavior of bay leaves [17], convective drying behavior of parsley [14], hot air drying behavior of tarragon leaves [15].

Effective moisture diffusivity values for drying of corn husks

The effective moisture diffusivities (D_{eff}) of microwave dried corn husks were calculated from the Fick's diffusion model and the results are given in Table 3. Chopped corn husks were placed in the microwave oven as a thin layer. That can be assumed as an infinite slab. L is taken as the thickness of the corn husk layer in Eqs. (2-4). As can be seen from Table 3 the D_{eff} values increased with increasing microwave powers, as expected.

Table 3. Effective moisture diffusivity values of the microwave dried corn husks.

Microwave Output Power (W)	D_{eff} ($m^2.s^{-1}$)	R^2
180	2.264E-10	0.9803
360	4.132E-10	0.9886
540	5.393E-10	0.9975
720	5.999E-10	0.9828
900	8.941E-10	0.9980

Panchariya *et al*. [8] investigated the drying kinetics of black tea between 80 and 120 °C in hot air and the effective moisture diffusivities varied from 1.141×10^{-11} to 2.98×10^{-11} $m^2.s^{-1}$ over the temperature range. Similarly, Doymaz [3] reported that the effective moisture diffusivities of mint for the temperature range 35-60°C ranged between 3.067×10^{-9} and 1.941×10^{-8} $m^2.s^{-1}$. Several researchers studied the microwave treatment of leafy plants such as mint and *Pandanus amaryllifolius* leaves which have a similar structure with corn husks. Ozbek and Dadali [18] reported that the effective moisture diffusivities of mint varied from 0.3982×10^{-10} to 2.0732×10^{-10} $m^2.s^{-1}$ for the power range from 180 to 900 W. Similarly, Rayaguru and Routray [16] calculated the D_{eff} value for *Pandanus amaryllifolius* as 1.99×10^{-7}-5.35×10^{-8} $m^2.s^{-1}$ for the power range from 180 to 720 W.

In processes where energy is involved, the temperature dependence of the reaction rates is expressed in terms of the Arrhenius equation. In the microwave drying process, where the temperature cannot be measured accurately, Arrhenius equation can be used as the modified form given in Eq. (6) [18]:

$$k=k_0\exp\left(-E_a\frac{m}{P}\right) \quad (6)$$

where k is the drying rate constant obtained using Page equation (min^{-1}). k_0 is the pre-exponential constant (min^{-1}). E_a is the activation energy ($W.g^{-1}$). P is the microwave power (W) and m is the mass of sample (g).

In the above-referred paper [18], the modified Arrhenius equation was used to define the dependence of a reaction rate constant on $m.P^{-1}$ where the mass of dried sample was increasing at constant microwave power. The same form of the equation was used in this study with the difference that the mass of the sample was kept constant while the microwave power used for drying operation was changed.

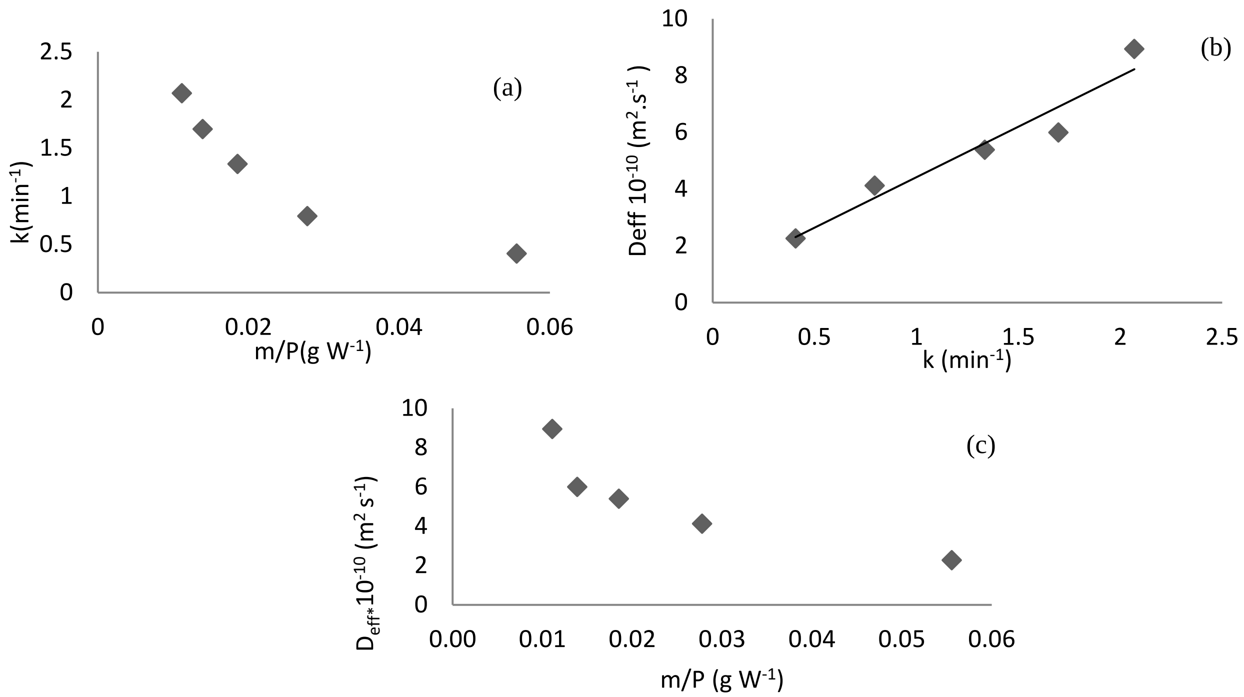

Fig. 3. (a) Relationship between the drying rate constant (k) of Page model and the sample mass /power ratio, (b) Relationship between the drying rate constant (k) and the effective moisture diffusivity (D_{eff}) for microwave drying of corn husks (■ calculated data; - model), (c) Relationship between the effective moisture constant and the sample mass.

The relationship between k and $m.P^{-1}$ is shown in Fig. 3a. Reduced chi-square (χ^2), RMSE and coefficient of determination (R^2) were found to be 0.01669, 0.1119 and 0.972, respectively. The k_0 and E_a values were estimated to be 3.443 min^{-1} and 49.350 $W.g^{-1}$, respectively. It was observed that the value of the drying rate constant (k) increased with the increase in microwave output power. By considering the Page model and the modified form of the Arrhenius equation together, (using the calculated value of k in the Page model) the constant n was found to be 1.065 as an arithmetical average for microwave drying of corn husk, and so it is possible to estimate the moisture ratio for a specific time or *vice versa*. The relationship between the drying rate constant (k) and the effective moisture diffusivity (D_{eff}) for microwave drying of corn husks is also shown in Fig. 3b. The result is consistent with that of Ozban and Dadali [18]. The researchers reported that the drying curve becomes steeper with the increase in microwave output power which indicates a faster drying of the product.

The activation energy was calculated by using the modified Arrhenius type exponential model as given in Eq. (7) [18]:

$$D_{eff}=D_0\exp\left(-E_a\frac{m}{P}\right) \quad (7)$$

where D_{eff} is the effective moisture diffusivity ($m^2.s^{-1}$), D_0 is the pre-exponential factor ($m^2.s^{-1}$), E_a is the activation energy ($W.g^{-1}$), P is the microwave power (W) and m is the mass of the sample (g). Similarly, the relationship between D_{eff} and m/P is given in Fig. 3c. Reduced chi-square (χ^2). RMSE and coefficient of determination (R^2) were found to be 1.331×10^{-20}, 9.989×10^{-11} and 0.924, respectively. D_0 and E_a were estimated as 9.678×10^{-10} $m^2.s^{-1}$ and 27.149 $W.g^{-1}$, respectively.

Results for powder properties

Dried products are usually ground to uniform size for further utilization. In this study, powdered form of dried corn husks was aimed to be suitable for different applications. The results for the powder properties of microwave dried corn husk powders are shown in Table 4. The tapped and bulk density values of corn husk powders range between 135-299 and 176-349 kg/m^3, respectively. Average wettability time (s) of husk powders decreased with increasing microwave power. This might be caused by the effect of the residual moisture content. Goula and Adamapoulos [11] reported that the residual moisture content, which significantly affects the operational conditions of the powder, affects wettability. The flowability and cohesiveness properties of microwave dried corn husk powders in

Table 4. Powder properties of the microwave dried corn husk powders.

Properties	Microwave Power (Watt)				
	180	**360**	**540**	**720**	**900**
Tapped density (kg/m^3)	200±9.8^b	135±3.8^a	240±2.9^b	229± 11.2^b	299± 7.9^c
Bulk density (kg/m^3)	240±7.9^b	176± 4.6^a	284±13.5^b	267±0.1^b	349± 10.8^c
Wettability (s)	497.5± 3.5^e	268.5 ± 4.9^d	121.0 ± 1.4^b	184.5±9.2^c	48.5±13.4^a
Flowability (CI)	Very good	Fair	Good	Very good	Very good
Cohesiveness (HR)	Low	Intermediate	Low	Low	Low

$^{a-e}$ Different letters in the same row indicate a significant difference between averages at P<0.05

terms of Carr Index and Hausner ratio were evaluated. The classification of powder flowability based on the Carr index (CI) is very good (<15), good (15-20), fair (20-35), bad (35-45), and very bad (>45).

The powder cohesiveness based on the Hausner Ratio (HR) is classified as low (<1.2), intermediate (1.2-1.4), and high (>1.4) [10]. According to powder properties, flowability and cohesiveness values of husk powders were generally found to be very good and low, respectively. These results showed the acceptability of the obtained powders for easy flowing and easy dosage to be used in powder formulations.

CONCLUSIONS

Drying kinetics of corn husk powders were investigated in a domestic microwave oven at different microwave powers (180-900W). Depending on the analysis of the results, a considerable falling drying rate was observed and the drying time of corn husk slices decreased with increasing microwave power. By evaluation of the eleven semi-empirical drying models by comparing the coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE), Page equation was found to satisfactorily describe the kinetics of microwave drying of corn husks. The drying rate constant (k) of the Page model generally increased with increasing microwave powers.

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МАТЕМАТИЧНО МОДЕЛИРАНЕ НА МИКРОВЪЛНОВО СУШЕНЕ В ТЪНЪК СЛОЙ НА ЦАРЕВИЧНИ ОБВИВКИ И ИЗСЛЕДВАНЕ СВОЙСТВАТА НА ПРАХА

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(Резюме)

Целта на тази работа е да се изследва ефекта на микровълновата енергия на кинетиката на сушенето на нарязани обвивки и да се определят свойствата на получения прах след сушенето. Процесът на сушенето е изследван с помощта на 11 общо-приети тънкослойни модели. Получените прахове са анализирани за влагосъдържание, водна активност, цвят, плътност, омокряемост, течливост, кохезивност. Допълнително ефективният коефициент на дифузия на влагата и активиращата енергия на обвивките е изчислена от данните за сушенето. Резултатите показват, че скоростта и времето на сушене значително намаляват с повишаването на микровълновата енергия. Между всички използвани модели този на Page е намерен като най-задоволителен за описанието на кинетиката на микровълновото сушене на царевичните обвивки. Ефективният коефициент на дифузия на влагата варира от 2.264×10^{-10} до 8.941×10^{-10} m^2s^{-1}.