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CONVECTIVE DRYING KINETICS OF GROUNDNUT EXTRACTION CAKE

KINETIKA KONVEKTIVNOG SUŠENJA EKSTRAKCIONE POGAČE KIKIRIKIJA

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ABSTRACT

The groundnut contains valuable edible oil (45-60 %), proteins (20-30 %), carbohydrates (18-20 %), essential vitamins and minerals. Groundnut seeds are used for the production of imitation milk containing 15.92 g /100 g of total solids, i.e. 5.74 g/100 g of fat, 4.24 g/100 g of carbohydrate, 5.58 g/100 g of protein, and 0.34 g/100 g of ash. The groundnut extraction cake examined in this paper was convectively dried at air temperature 80 °C and 90 °C for different periods of time (0-120 min). The moisture content of the groundnut extraction cake totaled 63.01 %. The following models were used to fit the simulation and experimental data obtained for the convective drying kinetics of the groundnut extraction cake under consideration: Page, Modified Page, One- and Two-Term Exponential, Cubic (Sigmoid), Exponential, Vega-Galvez, Logistic and Rational. The Page model had the best goodness of fit at air temperature 80 °C, whereas the Exponential model had the best goodness of fit at 90 °C due to the highest coefficient of determination (R^2) and lower Rmse and Sse values.

***Key words**: groundnut, imitation milk, extraction, drying, Page/exponential model.*

REZIME

Kikiriki sadrži vredno jestivo ulje (45-60%), proteine (20-30%), ugljene hidrate (18-20%), esencijalne vitamine i minerale. Seme kikirikija koristi se za proizvodnju imitacije mleka koje sadrži 15,92 g/100 g ukupne suve materije supstance, odnosno 5,74 g/100 g masti, 4,24 g/100 g ugljenih hidrata, 5,58 g/100 g proteina i 0,34 g/100 g pepela. Pogača iz ekstrakcije kikirikija koja se razmatra u ovom radu je konvektivno sušena na temperaturi vazduha za sušenje od 80 °C i 90 °C u različitim vremenskim periodima (0-120 min). Sadržaj vlage u pogači kikirikija iz ekstrakcije iznosio je 63,01 %. Korišćeni su sledeći modeli, kako bi se složili simulacioni i eksperimentalni podaci, dobijeni za kinetiku konvektivnog sušenja pogače kikirikija nakon ekstrakcije: Page, Modifikovana Page, jednostruki i dvostruki eksponencijalni, kubni (sigmoidna), Vega-Galvez i dr. Model Page imao je najbolje podudaranje pri temperaturi vazduha 80 °C, dok je eksponencijalni model imao najbolje podudaranje pri temperaturi vazduha za sušenje od 90 °C, što pokazuje najveći koeficijent determinacije (R2) i niže vrednosti Rmse i Sse.

***Ključne reči:** kikiriki, imitacija mleka, ekstrakcija, sušenje, Page/eksponencijalni model.*

INTRODUCTION

The groundnut (Arachis *hypogaea* L.) is an important local food crop in southern regions of Turkey, especially the Provinces of Adana and Osmaniye where 81 % of the total Turkish groundnut volume (141,000 tons in 2015) is produced (*Dogaka, 2015*). The groundnut provides a source of proteins and edible oil, which are considered highly valuable for human and animal nutrition in many countries. It contains beneficial edible oil (45-60%), proteins (20-30%), carbohydrates (18-20%), essential vitamins and minerals (namely vitamin A, vitamin E, folate, Mg, Zn, Fe, Ca), as well as dietary fibers (*Griel et al., 2004*; *Mattes et al., 2008*). The nutritional values of groundnuts have led to an increase in their consumption in numerous respects, one of which is the production of imitation milk (*Yadav et al., 2010*). A number of studies suggest that traditional and economic reasons limit the use of dairy products and promote the idea of reducing their use as a source of probiotic agents, or even supplanting dairy products by imitation milk products from other materials such as fruits, vegetables or cereals (*Murevanhema and Jideani, 2013*). Vegetable milk products are beneficial to human beings due to high protein, fatty acid and mineral contents, which are considered highly valuable for nutrition (*Murevanhema ans Jideani, 2013; Wang et al., 2007*). Imitation milk may be produced by grinding full-fat groundnuts and soaking them in water to get the groundnut slurry followed by filtration (*Chang and Beuchat, 1992; Isanga and Zhang, 2009*). Alternatively, it may be produced by grinding unsoaked roasted groundnuts, i.e. raw full-fat groundnuts, or partially defatted groundnuts to form flour to which water may be added to get an emulsion (*Aidoo et al., 2010*). It has been reported that groundnut milk contains 5.74 g/100 g of fat, 4.24 g/100 g of carbohydrates, 5.58 g/100 g of proteins, and 0.34 g/100 g of ash (*Isanga&Zhang,* 2009).The remaining portion of extracted groundnut cake contains a great quantity of proteins, carbohydrates and oil, which can be preserved by drying. Conventional drying is a technique used for food preservation in a manner that energy is absorbed by water located in the materials being dried. High vapor pressure occurs in the centre of the material, allowing the rapid transfer of moisture to the surrounding vacuum and preventing the structural collapse (*Figiel, 2010*). The most important factor of conventional heating is temperature which enhances drying and evaporation rates (*Sharma et al., 2011*). The generated heat results in a rapid mass transfer and forms a high vapor pressure difference between the center and the surface of the material (*Gaware et al., 2010*). Mathematical models are important for determining the drying parameters of food materials (*Gamli, 2011*). These models facilitate the selection of the most suitable operating conditions in order to describe the drying equipment or minimize the drying time for the final product specifications.

The purpose of this paper is to determine the effect of temperature on the drying kinetics of groundnut extraction cake and to fit the experimental data to the mathematical models available in the literature.

MATERIAL and METHOD

Materials

The groundnut cake examined in the present study was obtained from groundnut seeds during the production of imitation milk. The initial and final moisture contents of the groundnut cake were determined using the conventional method (*Gaware et al., 2010*).

Methods

The drying treatment was performed using a laboratory scale dryer. The groundnut cake was placed in a drying plate (8 mm thick and 120 mm in diameter) and convectively dried at air temperature 80 °C and 90 °C. The groundnut cake moisture loss was recorded at regular time intervals during the drying process with an accuracy of 0.1 g. The drying process was carried out to a final groundnut cake moisture content of 2-3 %.

Drying Characteristics of Groundnut Cake

A number of theoretical equations are used for describing the drying kinetics of food materials according to the Fick's second law of diffusion. Supposing the uniform initial moisture distribution, negligible external resistance, constant diffusivity and negligible shrinkage, the model is as follows:

$$Mr=[M-Mc]/[Mo-Mc]= [8/\pi^2]\exp[\pi^2 Deff/4L^2]$$

where M is the moisture content at any time (kg water/kg dry solid), Mo is the initial moisture content (kg water/kg dry solid), and Mc is the equilibrium moisture content of the food material.

The equation can be written in a simplified form as follows:

$$Mr= a.\exp(-k.t)$$

where a and k are constants, and t is the drying time in minutes (k and Deff (moisture diffusivity, m^2/s) can be obtained from $k=\pi^2 Deff/4.L^2$).

Theoretical equations for describing the drying process of food materials are listed in Table 1. The Page model is advised for drying fruits and vegetables such as peppers, apricots and purslane (*Gamli, 2011*), whereas the Logaritmic (Exponential) model is advised for the thin-layer drying of olive cakes and rose hips (*Akpinar & Biçer, 2007*).

Fitting of the Drying Data

The error sum of squares (Sse), the coefficient of determination (R^2) and the root-mean-square error (Rmse) were used to describe the drying process of groundnut cake. The software package Matlab (R2017b) was used for numerical evaluations.

Table 1. Mathematical models and references that being used for drying process of food materials

	Equation	References
Modified Page	$y=\exp(-k.t)^n$	*Kashaninejad&Tabil 2004*
Exponential	$y=a.\exp(-k.t^n)$	*Gamli.2011*
Logistic	$y=b/((1+a.\exp(k.t))$	*Gamli et al.2018*
Page	$y=\exp(-k.t^n)$	*Kashaninejad&Tabil 2004*
Cubic	$y=a+b.t+c.t^2+d.t^3$	*Doymaz et al.2004*
Vega-Galvez 2	$y=\exp(n+k.t)$	*Vega-Galvez et al.2010*
Rational	$y=[(a+b.t)/(1+c.t+d.t^2)]$	*Gamli et al.2018*
One term of exponential	$y=a.\exp(b.t)$	*Akpinar&Biçer 2007*
Two term of exponential	$y=a.\exp(b.t)+c.\exp(d.t)$	*Akpinar&Biçer 2007*
Hii et al.	$y=a.\exp(-b.x^n)+c.\exp(-d.x^n)$	*Gamli et al.2018*

RESULTS and DISCUSSION

The groundnut extraction cake was convectively dried at air temperature 80 °C and 90 °C. The moisture ratios of groundnut cake samples were illustrated in Figure 1. The groundnut cake contained around 11.8 % of oil, 13.9 % of proteins, 9.3 % of carbohydrates, and 1.85 % of ash. As can be seen from Figure 1, the moisture ratio decreases with the increasing drying time, and there was no constant rate period because the drying process took placed in a falling rate period. The rate of moisture removal from the groundnut cake was higher at higher drying temperatures, and it was similar to that obtained for coconut press cake, olive cake and olive oil pomace by other authors (*Akpinar&Biçer, 2007; Jena&Das, 2007; Gögüs&Maskan, 2006*). The initial moisture content of the groundnut cake was 63.01% (w.b), and it decreased to 2-3% (w.b) at the end of the drying process.

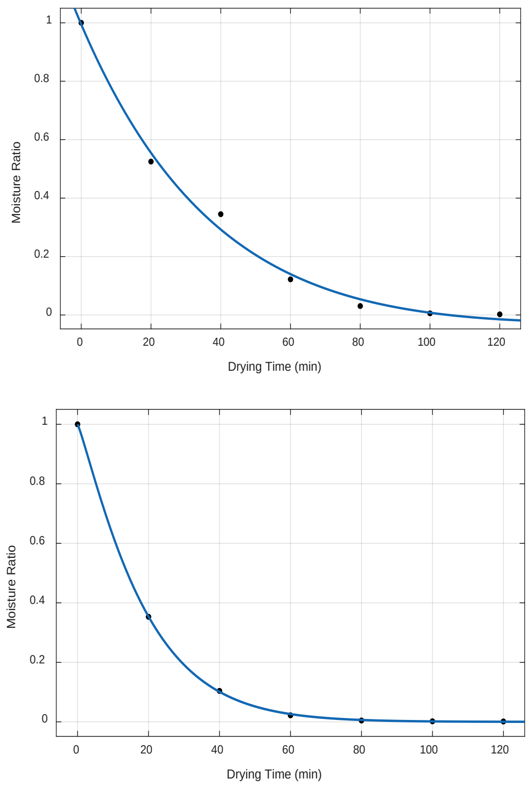

Fig. 1. Fittings of mathematical modelling of extraction cake of groundnut for drying curves (80 and 90 °C)

Several mathematical equations are used for describing the drying curve of food materials. The drying kinetics and curve fitting procedures of the groundnut cake were examined using the following models: Page, Modified Page, Exponential, Rational, Sigmoid, Logistic,Vega-Galvez, One- and Two-Term Exponential and Hii et al. The model constants and fitting of the experimental results were illustrated in Table 2 and 3 for drying air temperatures of 80 °C and 90 °C. The coefficient of determination (R^2), the root-mean-square error (Rmse) and the error sum of squares (Sse) were used for describing the model's suitability for the groundnut cake drying. Of all the models tested, the Page model had the best goodness of fit at air temperature 80 °C, whereas the Exponential model had the best goodness of fit at 90 °C due to the highest coefficient of determination (R^2) and lower Rmse and Sse values (Table 2 and 3).

The Page model constant k is the drying constant which characterizes the rate of moisture removal from the food material per unit of time. The constant k values obtained varied between 0.0196-0.0338 for air temperature 80 and 90 °C respectively, whereas the n values obtained varied between 1.13 and 1.143 for air temperature 80 and 90 °C respectively. In the case of olive-waste cake, k and n varied between 0.00327 -0.0181 and 1.096-1.181 for drying temperatures of 50-90 °C (*Grupta et al., 2002*), whereas k and n values varied from 1.1985 to 1.290 and from 0.003 to 0.006 for tomato drying (*Doymaz, 2007*). These results are in agreement with the results obtained in the present study.

The groundnut cake moisture diffusivity values were obtained by plotting the experimental drying data, indicating that Ln Mr versus time gives a straight line. The slope of the straight line of equation gives k as follows:

$$k = \pi^2 . Deff / 4 . L^2$$

where L is the half-thickness of the sample.

The moisture diffusivity of the groundnut cake (Deff (m^2/s)) increased with the increasing drying air temperature, and it varied from 1.405 10^{-6} to 2.61 10^{-5} (m^2/s) for 80 °C and 90 °C, respectively. The diffusivity of tomato samples increased with the increasing drying temperature and varied from 5.86 10^{-9} to 2.505 10^{-8} (m^2/s) (*Gamli, 2011*). Furthermore, the Deff values varied from 8.10 $^{-10}$ to 2.17 10^{-9} (m^2/s) for grape pulp for 70-110 °C (*Doymaz&Akgün, 2009*), from 0.702 10^{-9} to 3.32 10^{-9} (m^2/s) for coconut press cake for 65-75 °C (*Jena&Das, 2007*), and from 5.65 10^{-10} to 7.53 10^{-10} (m^2/s) for pre-treated tomato products for 55-70 °C, respectively (*Doymaz et al., 2004*). The results obtained showed that the moisture diffusivity values obtained for the groundnut cake examined in this paper were higher than those obtained for tomato, coconut press cake and grape pulp due to the aqueous structure of the groundnut cake obtained from groundnut milk production.

CONCLUSION

The groundnut cake examined was convectively dried at air temperature 80 °C and 90 °C to a final moisture content of 2-3% (w.b). The experimental data obtained were predicted using the following models: Page, Modified Page, One- and Two-term Exponential, Sigmoid, Vega-Galvez, Logaritmic (Exponential), Logistic and Rational. The Page model had the best goodness of fit at air temperature 80 °C, whereas the Exponential model had the best goodness of fit at 90 °C due to the highest coefficient of determination (R^2) and lower Rmse and Sse values. The moisture diffusivity values increased with the increasing drying temperature and ranged from 1.405 10^{-6} to 2.61 10^{-5} (m^2/s) for the groundnut cake examined.

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Table 2. Model constants and regression coefficients of mathematical models at 80 °C

Models	80 C								
	a	b	c	d	n	k	R^2	Rmse	Sse
Modified Page	-	-	-	-	0.0775	0.4121	0.9892	0.0421	0.00888
Exponential	0.9941	-	-	-	1.136	0.0191	0.9914	0.0419	0.00703
Lojistic	2.6	1.618	-	-	-	0.0403	0.9917	0.0412	0.00681
Page	-	-	-	-	1.143	0.0338	1.000	0.00254	3.23 10-5
Cubic (Sigmoid)	-0.0244	0.985	0.00020	-5.6 10^{-7}	-	-	0.9939	0.0409	0.00503
Vega-Galvez 2	-	-	-	-	0.007	-0.0321	0.9893	0.0420	0.00882
Rational	-611.5	1	2060	-158.2	-	-	0.9434	0.1245	0.0465
One term exponential	-0.0321	1.007	-	-	-	-	0.9893	0.0420	0.00882
Two term exponential	-0.0186	2.19e^4	-2.18e^4	-0.0186	-	-	0.9941	0.040	0.00482
Hii et al.	0.625	-2.718	3.718	0.313	-	0.565	0.9841	0.0807	0.0130

Table 3. Model constants and regression coefficients of mathematical models at 90 °C

Models	90 C								
	a	b	c	d	n	k	R^2	Rmse	Sse
Modified Page	-	-	-	-	1.302	0.0405	0.9992	0.0117	0.000688
Exponential	0.9999	-	-	-	0.0338	1.143	1.000	0.00284	3.23e^{-5}
Lojistic	1.709	2.719	-	-	0.0679	-	0.9999	0.00316	4.01e^{-6}
Page	-	-	-	-	1.13.	0.0196	0.9914	0.0376	0.00706
Cubic (Sigmoid)	0.984	-0.0384	0.00047	-1.9 10^{-6}	-	-	0.9953	0.0358	0.00385
Vega-Galvez 2	-	-	-	-	-0.0542	0.00285	0.9992	0.0116	0.00068
Rational	1	-0.0104	0.00063	0.00306	-	-	0.9998	0.00782	0.000183
One term exponential	1.003	-0.0542			-	-	0.9992	0.0116	0.000686
Two term exponential	15.9	-0.0395	-14.9	-0.0387	-	-	0.9998	0.0069	0.000143
Hii et al.	0.131	1.463	0.868	0.0212	-	1.251	1.000	0.00269	1.45e^{-5}

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