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AGRONOMSKI FAKULTET U
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MODEL OF CONVECTIVE DRYING OF BLACK CHOKEBERRY (*ARONIA MELANOCARPA* L.)

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Abstract: Drying kinetics of fresh uncrushed chokeberries (*Aronia melanocarpa* L.) was analyzed by the convective method at temperatures of 50, 60 and 70 °C. The experimental results were fitted using eight models for the moisture ratio (*MR*), and four models for dehydration ratio (drying speed, *DR*). The modified Page and the Logarithmic equation were successfully used to describe the *MR*, as well as the Polynomial and modified Gauss equation, for the *DR*. According to the efficiency of the convective drying (cost price, energy efficiency, constants of drying models), the recommended method of convective drying is the drying at 70 °C (the shortest dehydration time and the fastest dehydration speed).

Key words: convective drying, black chokeberry, moisture ratio, drying ratio

Introduction

Black chokeberry (*Aronia melanocarpa* L.), native to eastern North America, has become very popular in Eastern Europe and Russia (Valcheva-Kuzmanova and Belcheva, 2006), because of the high content of bioactive compounds (tannins, procyanidins, anthocyanins, phenolic acids, and quercetins) (Kim et al., 2012).

The new fruit products, such as fruit powders or snacks, are commercially available. In processing, the dehydration is probably the oldest and the most frequently used methods of fruit and vegetable preservation (Calín-Sánchez et al., 2015). The advantages of the dehydrating methods are the efficient preservation and long storage, prevention of microorganisms' development, cheaper and easier transport, the simple industry or laboratory equipment (Wojdyło et al., 2016). This method has many disadvantages: long dehydration time, high dehydration temperature, flavor and color degradation, tissue denaturation and material shrinkage (Figiel et al., 2010). The final quality of dehydrated chokeberries is defined by physical (texture, appearance, porosity, color) and (bio)chemical properties (vitamins, bioactive components, flavor) (Gawałek et al., 2017).

The aim of this study was to find the optimal model for the drying kinetics behavior of fresh chokeberries using a convective drying method at 50, 60, 70 °C.

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Material and methods

Material

Fruits of black chokeberry (*Aronia melanocarpa* L.) were collected in the village Kušići, located on Javor mountain (43°28'40.8"N, 20°03'35.7"E, Serbia), and immediately transported and dehydrated to the Faculty of Agronomy.

Methods

Convective drying was conducted in the dehydrator (Colossus CSS 5330, PRC) at temperatures of 50, 60 and 70 °C at atmospheric pressure, to the constant weight. Uncrushed chokeberries were placed in a tray of 320-mm diameter in a thin layer with a mass load of 3 kg m⁻², and at an air velocity of 0,25 m s⁻¹. The convective drying kinetics was based on mass losses of chokeberry (Szychowski et al., 2018). The moisture ratio (*MR*) is defined according to Equation 1:

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

M_t, *M_o* and *M_e* represent the moisture content achieved after convective drying time *t*, the initial moisture content, and the equilibrium moisture content, respectively. The value of equilibrium moisture content (*M_e*) usually is very low and can be deleted from Eq. (1) without a significant change in the value of *MR*.

The drying kinetics (drying ratio, *DR*) is a change in the total mass loss of fruits (*M_{i-1} - M_i*) in the interval of time between 2 measurements (*t_{i-1} - t_i*) on a particular tray during the convective drying (Equation 2, Petković et al., 2019).

$$DR = \frac{M_{i-1} - M_i}{t_{i-1} - t_i} \quad (2)$$

Origin8 software was used for the fitting basic convective drying models (Origin8, 2007). The best fitting of a specific model to the experimental data was evaluated using the coefficient of determination (*R*²) and the root means square error (*RMSE*). The model fit is better if the value of *R*² is closer to 1 and the *RMSE* value is closer to 0 (Petković et al., 2019).

Results and discussion

The decrease in the *MR* during convective drying was described using eight drying models (Table 1). All models were found as outstanding models. However,

Tabela 1. Model odnosa vlage (MR) primenjen na eksperimentalne krive sušenja
 Table 1. Model of the moisture ratio (MR) applied to the experimental drying curves

		Odnos vlage MR									
Model Model	Jednačina modela Model Equation	T (°C)	a	k	b	c	d	R ²	RSME		
Newton	$y=e^{-k \cdot x}$	50		0,0825				0,9903	0,0302		
		60		0,1261				0,9847	0,0587		
		70		0,1472				0,9941	0,0464		
Henderson-Pabis	$y=A \cdot e^{-k \cdot x}$	50	1,0548	0,0871				0,9937	0,0240		
		60	1,0817	0,1577				0,9866	0,0537		
		70	1,0671	0,1748				0,9909	0,0421		
Modified Page	$y=a \cdot e^{-k \cdot x^b}$	50	0,9908	0,0481	1,2005			0,9988	0,0102		
		60	0,9874	0,0790	1,2003			0,9910	0,0441		
		70	1,0039	0,1209	1,0969			0,9967	0,0358		
Logarithmic	$y=a \cdot e^{-k \cdot x} + c$	50	1,1111	0,0711		-0,0849		0,9990	0,0093		
		60	1,1319	0,0997		-0,1194		0,9939	0,0467		
		70	1,0641	0,1337		-0,0484		0,9973	0,0371		
Two-term	$y=a \cdot e^{-b \cdot x} + c \cdot e^{-d \cdot x}$	50	3,9353		0,0432	-2,9373	0,0366	0,9994	0,0517		
		60	10,5836		0,0665	-9,5749	0,0621	0,9936	0,0452		
		70	1,1445		0,1265	-0,1306	0,0345	0,9972	0,0278		
Midilli-Kucuk	$y=a \cdot e^{-k \cdot x^b} + c \cdot x$	50	0,9934	0,0562	1,0685	0,0000		0,9938	0,0590		
		60	0,9874	0,0791	1,1999	0,0000		0,9903	0,0440		
		70	1,0038	0,1208	1,0973	0,0000		0,9965	0,0357		
Weibull	$y=a \cdot b \cdot e^{-k \cdot x^c}$	50	0,0000	0,0481	-0,9908	1,2007		0,9988	0,0102		
		60	0,0000	0,0794	-0,9879	1,1985		0,9903	0,0441		
		70	0,0000	0,1209	-1,0039	1,0968		0,9965	0,0358		
Parabolic	$y=c+a \cdot x+b \cdot x^2$	50	-0,0578		0,0009	0,9975		0,9951	0,0387		
		60	-0,0879		0,0020	0,9817		0,9938	0,0461		
		70	-0,0956		0,0024	0,9527		0,9894	0,0399		

MR – moisture ratio, $MR = y$, $t = x$

Tabela 2. Model brzine sušenja (DR) primenjen na eksperimentalne krive sušenja
 Table 2. Model of the drying ratio (DR) applied to the experimental drying curves

		Brzina sušenja (g h ⁻¹) DR (g h ⁻¹)											
Model Model	Jednačina modela Model Equation	T (°C)	a	k	b	c	a ₄	a ₅	a ₆			R ²	
LangmuirEXT2	$y = (a + b \cdot x^c)^{-1}$	50	0,0178		0,0000250	3,5076						0,9861	
		60	0,0134		0,0000021	4,6648						0,9656	
		70	0,0096		0,0000130	4,0862						0,9836	
Polynomial	$y = a_0 + a_1 \cdot x + \dots + a_{n-1} \cdot x^{n-1}$	50	2,3992	a ₁	a ₂	a ₃	a ₄	a ₅	a ₆			R ²	
		60	-0,3231	66,5719	-27,7519	5,5439	-0,6267	0,0425	-0,0018			0,9829	
		70	0,0420	109,5508	-43,7958	8,3388	-0,9081	0,0598	-0,0024			0,9932	
Gauss Modified	$y = y_0 + \frac{a}{t_0} e^{\frac{z}{t_0}} + \frac{1}{t_0} \int_{-\infty}^z \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} dy,$ $z = \frac{x - x_c}{w} \cdot \frac{w}{t_0}$	50	-8,3258	a	x _c	w	t ₀					R ²	
		60	-21,7382	1357,3138	0,5721	0,4700	17,8626					0,9853	
		70	-15,5599	1757,7061	0,6997	0,7026	12,0650					0,9856	
Harris	$y = (a + b \cdot x^c)^{-1}$	50	0,0217	b	c							R ²	
		60	0,0186	0,0000000030	3,8401							0,9111	
		70	0,0130	0,0000000006	6,0725							0,7398	
					5,4667						0,8742		

DR – drying ratio, DR = y, t = x RSME – not appropriate parameter for the “peak” functions

the modified Page, the Logarithmic, and the Weibull were found as the best models taking into account the highest values of R^2 (means of \pm standard deviation, $0,9955 \pm 0,0040$, $0,9967 \pm 0,0026$, and $0,9952 \pm 0,0044$, respectively) and the lowest values of $RSME$ (means of \pm standard deviation, $0,0300 \pm 0,0177$, $0,0310 \pm 0,0194$, and $0,0300 \pm 0,0177$, respectively). The similar models were used to predict the drying behavior of many fruit materials, such as quinces (Szychowski et al., 2018), and plums (Živković et al., 2011). The drying constant a varied slightly and had values closed to 1. This parameter in the Weibull model was 0, so the model could be converted into the modified Page model. The higher temperature of the samples promoted higher values of constants k (in the modified Page, the Logarithmic, and the Weibull) and consequently higher drying rate which guarantees the shortening of drying time.

The change in the DR during convective drying was described using four drying models (Table 2). The Polynomial and the modified Gauss model were found as the best models (means of \pm standard deviation, $R^2 = 0,9912 \pm 0,0075$, $R^2 = 0,9889 \pm 0,0059$, respectively). An increase in a drying temperature was in a correlation to the increase of the drying constants a , x_c , and w , and the decrease of the drying constants y_o and t_o of the GaussMod model. The results are according to the results as in research by Mitrović et al. (2012). The constants a_1 , a_3 , and a_5 were increased with the temperature growth, unlike the decrease of constants a_2 , a_4 , and a_6 .

Conclusions

Drying kinetics of chokeberries dried by convective techniques at 50, 60, or 70 °C were assessed. The modified Page, and the Logarithmic equation were successfully used, as a models, to describe the moisture ratio (MR) of chokeberry fruits ($R^2 = 0,9955 \pm 0,0040$, $9967 \pm 0,0026$ respectively; $RSME = 0,0300 \pm 0,0177$, $0,0310 \pm 0,0194$, respectively), as well as the Polynomial and the modified Gauss equation, as far as drying ratio (drying speed, DR) was concerned ($R^2 = 0,9912 \pm 0,0075$, $0,9889 \pm 0,0059$, respectively). According to the efficiency of the process (cost price, energy efficiency, constants of drying models), the recommended convective drying method was convective drying at 70 °C (the shortest dehydration time and the fastest dehydration speed).

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MODEL KONVEKTIVNOG SUŠENJA CRNEARONIJE (*ARONIA MELANOCARPA L.*)

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Izvod: Kinetika sušenja svežih celih plodova aronije (*Aronia melanocarpa*L.) analizirana je konvektivnom metodom na temperaturama od 50, 60 i 70 °C. Rezultati eksperimenta su postavljeni na osnovu osam modela za promenu odnosa vlage (MR) i četiri modela za promenu ukupnih masa plodova (brzina sušenja, DR). Modifikovana Page i Logaritamska jednačina uspešno su korišćene za opisivanje MR, kao i polinomne i modifikovane Gaussove jednačine, za DR. Prema efikasnosti konvektivnog sušenja (cena koštanja, energetska efikasnost, konstante modela sušenja), preporučeni metod konvektivnog sušenja je sušenje na 70 °C (najkraće vreme i najbrža brzina dehidracije).

Ključne reči: konvektivno sušenje, crna aronija, promena odnosa vlage, brzina sušenja

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