

CONVECTIVE DRYING KINETICS OF OSMOTICALLY PRE-TREATED POTATO SLICES

KINETIKA KONVEKTIVNOG SUŠENJA OSMOTSKI PREDTRETIRANIH KRIŠKI KROMPIRA

Vangelce MITREVSKI^{*}, Cvetanka MITREVSKA^{**}, Mirko BABIĆ^{***}, Tale GERAMITCIOSKI^{*}, Borce MITREVSKI^{****}
^{*}Faculty of Technical Sciences, 7000 Bitola, Makedonska Falanga 33
^{**}Faculty for Safety Engineering, Sveti Nikole
^{***}Faculty of Agriculture, Novi Sad, Serbia
^{****}Center of Energy Efficiency Bobi Turs, Bitola
e-mail: vangelce.mitreovski@uklo.edu.mk

ABSTRACT

In the food industry, convective drying is a widely used method due to its applicability to many food materials. Besides this advantage of the convective drying method, there are several shortcomings related to the rehydration capacity, low quality of dried material, loss of color, flavour, and nutrient of the final dried materials. In this paper, the convective drying kinetics of osmotically pre-treated potato slices (variety Carrera) were analyzed. Thin-layer drying kinetics of potato slices at four drying air temperatures 40, 50, 60 and 70°C and two drying air velocities 1 and 2 ms⁻¹ were obtained on the experimental setup. For an approximation of the experimental data with regard to the moisture ratio three thin-layers drying, models from scientific literature and the model of Mitrevski et al., were used. For each model and data set the statistical performance index, ϕ chi-squared, and χ^2 , values were calculated and models were ranked afterward.

Keywords: potato, osmotically pre-treated, thin-layer drying model.

REZIME

U prehrambenoj industriji, konvektivno sušenje je široko korišćena metoda zbog primenljivosti za veliki broj prehrambenih materijala. Ipak, pored ove prednosti, ovaj metod ima niz nedostataka povezanih sa kapacitetom rehidratacije, niskim kvalitetom osušenog materijala, gubitakom boje, ukusa i važnih nutricionističkih sastojaka finalnog proizvoda. Zbog ovih razloga neophodan je predtretman materijala poput blanširanja, tretmana organskim kiselinama i osmotske dehidratacije. Osmotska dehidratacija je proces koj se koristi kako bi se smanjio sadržaj vode u ćelijskim tkivima voća i povrća. Kriške krompira stavljene su u posudu od 300 ml koja je sadržala osmotski rastvor, a nakon toga je posuda postavljena u vodeno kupatilo sa regulacijom temperature. Osmotski predtretman je izveden sa hipertoničnim rastvorom saharoze od 40°Bx na temperaturi od 40°C uz konstantni protok rastvora tokom 2 h. Eksperimentalni podaci kinetike sušenja kriški krompira u tankom sloju dobijeni su za četiri temperature vazduha sušenja 40, 50, 60 i 70°C i dve brzine vazduha sušenja 1 i 2 ms⁻¹. Eksperimenti su izvršeni u eksperimentalnom laboratorijskom modelskom postrojenju za ispitivanje kinetike konvektivnog sušenja, koja je projektovana tako da simulira industrijsku sušaru. Za aproksimaciju eksperimentalnih rezultata kinetike sušenja korišćen je novorazvijeni matematički model. Podaci iz eksperimenta sušenja o odnosu trenutne i početne vlažnosti materijala aproksimovani su novim generisanim modelom sušenja tankosloja, a relevantan uticaj određen je statističkim pokazateljem, ϕ i testom χ -kvadrat vrednosti, χ^2 . Rezultati korišćene statističke analize pokazuju da sopstveni model ima bolje statističke pokazatelje nasuprot poznatih modela za tanki sloj, koji se danas sa uspehom koriste, a prikazani su u dostupnoj naučnoj literaturi

Cljučne reči: krompir, osmotski predtretman, tankoslojni model sušenja.

INTRODUCTION

The potato is a vegetable that is a good source of minerals such as magnesium, phosphorous, iron, copper and zinc as well as vitamin C and B-complex vitamins such as thiamin, niacin, riboflavin and pyridoxine (vitamin B-6) (Mitrevski et al., 2015).

Convective hot-air drying is the most widely used method for the preservation of dehydrated fruits and vegetables. The main disadvantages of this classical drying process are the low dehydration capacity of the dried materials, the decrease in nutritive values and the material colour changes during drying (Kanevce et al., 1998).

Osmotic dehydration was used as pre-treatment to reduce air-drying time, limited heat damage and improve the textural quality, vitamin retention, flavour enhancement and colour stabilization (Pavkov et al., 2011; Radojcin et al., 2015).

Several pieces of research experimentally investigated drying kinetics for combined osmotic-convective drying of various fruits and vegetables: peach (Pavkov et al., 2011), potato (Singh et al., 2014), quince (Radojcin, et al., 2015), apple (Mitrevski et al., 2019).

Thin-layer drying models are important tools in the mathematical modeling of drying processes. They are often used to estimate drying time and generalize drying curves and have a wide application due to their ease of use and requirement of less data unlike in complex mathematical models.

In the scientific literature, there are many pieces of research on the experimental studies and mathematical modelling of the drying behaviour of various fruits and vegetables such as potato (Mitrevski, 2005), apple (Mitrevski et al., 2013), quince (Mitrevski, 2015), pear and quince (Mitrevski et al., 2018).

The objectives of this study were: (i) to carry out the osmotic dehydration of potato slices at 40 °C using 40 °Brix sucrose solutions, followed by convective hot air drying, and to study the effect of the drying air temperatures from 40 to 70 °C and drying air velocities from 1 and 2 ms⁻¹ on the mass transfer.

MATERIAL AND METHODS

Raw material. Fresh potato variety 'Carrera' was used in the experimental part of the study. The spherical samples with a thickness of 3±10⁻¹ mm were used in the drying experiments.

Osmotic dehydration. The potato slices were pretreated using osmotic dehydration. The slices were placed in a 300 ml container containing sucrose osmotic solution with 40 °Bx on ambient temperature 40 °C and atmospheric pressure. Then, the container was placed in the water bath with temperature control. After a period of 2 h, the slices were rinsed with pure water to remove the solution and blotted with tissue paper to remove the excess water from the surface.

Convective drying. The pre-treated samples in osmotic solution were dried in an experimental setup designed to simulate an industrial convective dryer, (Mitreviski *et al.*, 2019). The drying experiments were performed at four drying air temperatures of 40, 50, 60 and 70°C, and two drying air velocities of 1 and 2 ms⁻¹, whereas the absolute air humidity remained constant at 0.0125 kg water kg⁻¹ dry air. The basic data on drying kinetics were collected by measuring changes in the mass of the samples during convective drying in an interval of 10 min.

The initial moisture content and the final moisture content of dried samples were determined gravimetrically using the hot air oven method at 105°C and atmospheric pressure for a period of 24 h. The experiments were replicated three times at each drying air temperature and drying air velocity. The average value of the moisture ratio was used for constructing the drying curves.

RESULTS AND DISCUSSIONS

In the majority of existing thin-layer drying models which are used for approximation of the experimental data of drying kinetics, the effect of drying air temperature and drying air velocity on the empirical parameters is not taken into account.

For an approximation of experimental data on the drying kinetics of potato slices three thin-layer mathematical models from scientific literature and the model of Mitreviski (Mitreviski *et al.*, 2019), were used (tab.1).

Table 1. Thin-layer drying models

Model	Name of model	Equation	References
M1	Midilli	$MR = A \exp(-k_1 \tau^B) + C \tau$	Midilli <i>et al.</i> , 2002
M2	Jena and Das	$MR = A \exp(-k_1 \tau + B \tau^{0.5}) + C$	Jena <i>et al.</i> , 2017
M3	da Silva	$MR = \exp(-A \tau - B \tau^{0.5})$	da Silva, <i>et al.</i> , 2014
M4	Mitreviski	$MR = A \exp(-k_1 \tau + B \tau^{0.5}) + (C + v^D T^E)$	Mitreviski <i>et al.</i> , 2019

*MR = M/M₀ moisture ratio; M_τ the moisture content at any time of drying (kg kg⁻¹ d.m.), M₀ initial moisture content (kg kg⁻¹ d.m.), A, B, C, D, E empirical coefficients, k₁ drying constant (min⁻¹), τ drying time (min⁻¹), v drying air velocity (ms⁻¹), T drying air temperature (°C)

The statistical performance features of those models were assessed based on the calculated average value of the performance index, φ, and the average χ², chi-squared value. The value of the performance index, φ, is calculated based on values of coefficient of determination, R², the root mean squared error, RMSE and the mean relative deviation, MRD (Ruiz-López *et al.*, 2009):

$$\phi = \frac{R^2}{RMSE \cdot MRD} \quad (1)$$

The higher values of the performance index, φ, indicate that the thin-layer drying model better approximates the experimental drying data.

The D'Agostino-Pearson test of normality is the most effective procedure for assessing goodness of fit for a normal distribution. This test is based on the individual statistics for testing of the residual population of skewness, z₁, and kurtosis, z₂, which values were calculated according to equations given in (Sheskin, 2011). Then the chi-squared, χ², value is computed with the equation (Sheskin, 2011):

$$\chi^2 = z_1^2 + z_2^2 \quad (2)$$

The tabled critical 0.05 chi-square value for degrees of freedom, df = 2 is χ² = 5.99. Therefore, if the computed value of chi-square is equal to, or greater than, either of the aforementioned values, the null hypothesis can be rejected at the appropriate level of significance (p > 0.95), i.e. the thin-layer drying model should be rejected (Sheskin, 2007).

The selection of a thin-layer model with a graphical evaluation of the residual randomness is also popular. If the thin-layer model is correct, then the residual should be only random independent errors with a zero mean, constant variance and arranged in a normal distribution. If the residual plots indicate a clear pattern, the model should not be accepted.

The method of multiple indirect non-linear regression and estimation methods of Quasi-Newton, Simplex, Simplex and quasi-Newton, Hooke-Jeeves pattern moves, Hooke-Jeeves pattern moves and quasi-Newton, Rosenbrock pattern search, Rosenbrock pattern search and quasi-Newton, Gauss-Newton and Levenberg-Marquardt from computer program StatSoft Statistica (Statsoft Inc., Tulsa, OK, <http://www.statsoft.com>), were used. Because the regression method, estimation method, the initial step size, the start values of parameters, convergence criterion and form of the function have a significant influence on the accuracy of estimated parameters, a large number of numerical experiments were performed (Mitreviski *et al.*, 2017).

Based on thin-layer data and each model from (tab. 2), the values of coefficient of determination and chi-squared were calculated. When the value for the coefficient of determination obtained from different estimation methods was different, the greatest value was accepted as relevant. After that, the models were ranked based on the average value of the performance index, φ_a, (tab. 2). From tab. 2 it is evident that model M4 i.e. Mitreviski *et al.*, model, has the highest value of performance index, φ_a = 183.63, (rank 1) in comparison with the other models. Also, it can be seen that all models have a smaller average value of, χ_a² than the tabled critical chi-square value.

In accordance with statistical criteria, the model of Mitreviski *et al.*, is able to correlate the experimental values of drying kinetics of potato slices with a 3.8% root mean squared error.

Table 2. Ranking of the models

Model	R ²	RMSE	MRD	ϕ_a	χ_a^2	Rank
M1	0.9816	0.0521	0.2619	71.938	3.1825	2
M2	0.9811	0.0536	0.2713	67.468	3.3616	4
M3	0.9804	0.0527	0.2722	68.345	3.3717	3
M4	0.9921	0.0381	0.1418	183.63	2.0112	1

Similar statistical performance of the model of Mitrevski *et al.*, was obtained for the experimental data of osmotically-convective dried apples (Mitreviski *et al.*, 2019).

The values of model parameters, A, B, C, D, E and F for the models M4 were estimated by fitting the models to an experimental moisture ratio data of potato slices using estimation methods that minimize the sum squares errors. The estimated values of parameters are given in tab. 3.

Table 3. The values of estimated parameters in model M4

Model	A	B	C	D	E	F
M4	1.097	0.029	0.031	-0.323	-0.278	-0.265

In fig. 1, the experimental and predicted values of moisture ratio with drying time at drying air temperature 40, 50, 60 and 70 °C for potato slices at drying air velocity of 2 ms⁻¹ are shown.

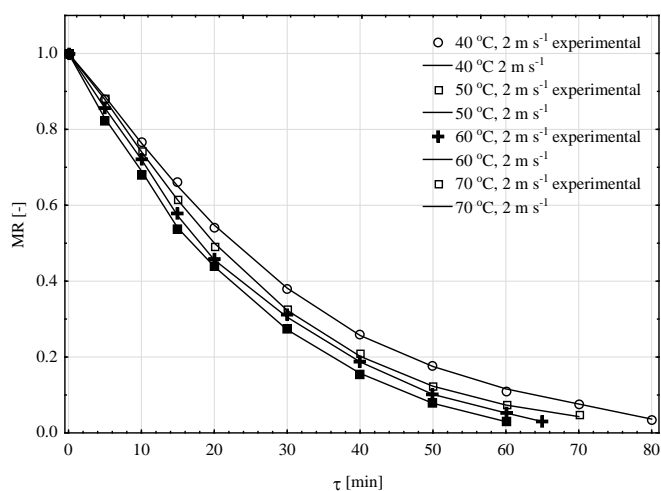


Fig. 1. Experimental and predicted moisture ratio for different air drying temperatures and drying air velocity of 2 ms⁻¹ approximated with the model of Mitrevski *et al*

From fig.1 is evident that has a good agreement between the experimental and predicted values of moisture data of potato.

Analyzing the residues on regression analysis for model M4, the plots of the residues against the predicted values did not indicate abnormal distribution.

CONCLUSIONS

In this study, osmotic dehydration was applied in order to evaluate the influence of pretreatment on convective drying of potato slices at four drying air temperatures and two drying air velocities. The experimental drying data in terms of moisture ratio were approximated with three thin-layer drying models from scientific literature and the model of Mitrevski *et al.* Based

on statistical parameters the model of Mitrevski *et al.*, has the best statistical performance when compared to existing literature thin-layer models. So, the model of Miteviski *et al.* can be used to simulate experimental drying curves of thin layer potato slices in the range of drying conditions. On the other hand, using a combination of convective drying with osmotically pretreated potato slices leads to a reduction in drying time compared with the convective drying method.

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