# MODEL OF CONVECTIVE DRYING OF BLACK CHOKEBERRY (*ARONIA MELANOCARPA* L.)

*Marko Petković[1], Igor Đurović[1], Nemanja Miletić[1], Alexander D. Lukyanov[2], Evgenia P. Klyuchka[2], Jovana Radovanović[1], Danila Y. Donskoy[2]*

**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.

[1]Univesity of Kragujevac, Faculty of Agronomy Čačak, Cara Dušana 34, Čačak, Serbia (marko.petkovic@kg.ac.rs, igor.djurovic@kg.ac.rs, n.m.miletic@kg.ac.rs, radovanovicjovana2@gmail.com);
[2]Don State Technical University, Ploshchad' Gagarina 1, Rostov-on-Don, Russian Federation (alexlukjanov1998@gmail.com, klyuchkae@mail.ru, dand22@bk.ru);

# 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:

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

$M_t$, $M_o$ 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 (*Me*) 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).

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

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 *ModelEguation* | *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 | $y=a-b\cdot e^{-k\cdot x^c}$ | 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 *ModelEguation* | *T* (°C) | *a* | *k* | *b* | *c* | | | | $R^2$ |
| LangmuirEXT2 | $y=(a+b\cdot x^{c-1})^{-1}$ | 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 |
| | | | $a_0$ | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $R^2$ |
| Polynomial | $y=a_0+a_1\cdot x+\dots+a_{n-1}\cdot x^{n-1}$ | 50 | 2,3992 | 66,5719 | -27,7519 | 5,5439 | -0,6267 | 0,0425 | -0,0018 | 0,9829 |
| | | 60 | -0,3231 | 109,5508 | -43,7958 | 8,3388 | -0,9081 | 0,0598 | -0,0024 | 0,9932 |
| | | 70 | 0,0420 | 153,4858 | -76,3756 | 18,3457 | -2,5584 | 0,2191 | -0,0117 | 0,9974 |
| | | | $y_0$ | *a* | $x_c$ | *w* | $t_0$ | | | $R^2$ |
| Gauss Modified | $y=y_0+\frac{a}{t_0}e^{\frac{1}{2}\left(\frac{\omega}{t_0}\right)^2-\frac{x-x_c}{t_0}}\int_{-\infty}^{z}\frac{1}{\sqrt{2\pi}}e^{\frac{-y^2}{2}}dy,$ $z=\frac{x-x_c}{w}-\frac{w}{t_0}$ | 50 | -8,3258 | 1357,3138 | 0,5721 | 0,4700 | 17,8626 | | | 0,9853 |
| | | 60 | -21,7382 | 1757,7061 | 0,6997 | 0,7026 | 12,0650 | | | 0,9856 |
| | | 70 | -15,5599 | 1427,7618 | 0,6594 | 0,5253 | 9,1999 | | | 0,9957 |
| | | | ***a*** | ***b*** | ***c*** | | | | | $R^2$ |
| Harris | $y=(a+b\cdot x^{c})^{-1}$ | 50 | 0,0217 | 0,0000003000 | 3,8401 | | | | | 0,9111 |
| | | 60 | 0,0186 | 0,0000000030 | 6,0725 | | | | | 0,7398 |
| | | 70 | 0,0130 | 0,0000000006 | 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 ± standard deviation, 0,9955 ± 0,0040, 0,9967 ± 0,0026, and 0,9952 ± 0,0044, respectively) and the lowest values of *RSME* (means of ± standard deviation, 0,0300 ± 0,0177, 0,0310 ± 0,0194, and 0,0300 ± 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 ± standard deviation, $R^2$= 0,9912 ± 0,0075, $R^2$= 0,9889 ± 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 weresuccessfully used,as a models, to describe the moisture ratio (*MR*) of chokeberry fruits ($R^2$ = 0,9955 ±0,0040, 9967 ± 0,0026 respectively; *RSME* = 0,0300 ± 0,0177, 0,0310 ± 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 ± 0,0075,0,9889 ± 0,0059, respectively). According to the efficiency of the process (costprice, energy efficiency, constants of drying models), the recommended convective drying method wasconvective drying at 70 °C (the shortest dehydrationtime and the fastestdehydration speed).

## References

Calín-Sánchez Á., Kharaghani A., Lech K., Figiel A., Carbonell-Barrachina Á.A., Tsotsas E. (2015). Drying kinetics and microstructural and sensory properties of black chokeberry (*Aronia melanocarpa*) as affected by drying method. Food and Bioprocess Technology 8(1), 63-74.

Figiel A., Szumny A., Gutiérrez-Ortíz A., Carbonell-Barrachina, A.A. (2010). Composition of oregano essential oil (*Origanum vulgare*) as affected by drying method. Journal of Food Engineering 98(2), 240-247.

Gawałek J., Domian E., Ryniecki A., Bakier S. (2017). Effects of the spray drying conditions of chokeberry (*Aronia melanocarpa* L.) juice concentrate on the physicochemical properties of powders. International Journal of Food Science and Technology 52(9), 1933-1941.

Kim H.G., Kim G.S., Park S., Lee J.H., Seo O.N., Lee S.J., Kim J.H., Shim J.H., El-Aty A.M.A., Jin J.S., Shin S. C. (2012). Flavonoid profiling in three citrus varieties native to the Republic of Korea using liquid chromatography coupled with tandem mass spectrometry: Contribution to overall antioxidant activity. Biomedical Chromatography 26(4), 464-470.

Mitrović O.V. (2012). Кинетика сушења и квалитет сушених плодова најзначајнијих сората шљива у Србији (Drying kinetics and quality of dried fruits of major plum cultivars grown in Serbia). Ph.D. Thesis. University of Belgrade, Faculty of Agriculture, Belgrade.

Origin8, Version 2007. OriginLab Corporation, Northampton, MA, USA.

Petković M., Đurović I., Miletić N., Radovanović J. (2019). Effect of convective drying method of chokeberry (*Aronia melanocarpa* L.) on drying kinetics, bioactive components and sensory characteristics of bread with chokeberry powder. Periodica Polytechnica Chemical Engineering 1, 1-9.

Szychowski P.J., Lech K., Sendra-Nadal E., Hernández F., Figiel A., Wojdyło A., Carbonell-Barrachina Á.A. (2018). Kinetics, Biocompounds, Antioxidant Activity, and Sensory Attributes of Quinces as Affected by Drying Method. Food and Bioprocess Technology 255(1), 157-164.

Valcheva-Kuzmanova S.V., Belcheva A. (2006). Current knowledge of Aronia melanocarpa as a medicinal plant. Folia Medica 48(2), 11-17.

Wojdyło A., Figiel A., Legua P., Lech K., Carbonell-Barrachina A. A., Hernández F. (2016). Chemical composition, antioxidant capacity, and sensory quality of dried jujube fruits as affected by cultivar and drying method. Food Chemistry 207(1), 170-179.

Živković M., Rakić S., Maletić R., Povrenović D., Nikolić M., Kosanović N. (2011.) Effect of temperature on the physical changes and drying kinetics in plum (*Prunus Domestica* L.) Požegača variety. Chemical Industry and Chemical Engineering Quarterly 17(3), 283-289.

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

*Marko Petković[1], Igor Đurović[2], Nemanja Miletić[3], Alexander D. Lukyanov[4], Eugenia P. Kluchka[5], Jovana Radovanović[6], Danila Y. Donskoy[7]*

**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

[1]Univerzitet u Kragujevcu, Agronomski fakultet Čačak, Cara Dušana 34, Čačak, Srbija (marko.petkovic@kg.ac.rs, igor.djurovic@kg.ac.rs, n.m.miletic@kg.ac.rs, radovanovicjovana2@gmail.com);
[2]Državni tehnički univerzitet Don, Trg Gagarina 1, Rostov na Donu, Ruska Federacija (alexlukjanov1998@gmail.com, klyuchkae@mail.ru, dand22@bk.ru);

UNIVERZITET U KRAGUJEVCU
AGRONOMSKI FAKULTET U ČAČKU

UNIVERSITY OF KRAGUJEVAC
FACULTY OF AGRONOMY
CACAK

# XXV SAVETOVANJE O BIOTEHNOLOGIJI

**sa međunarodnim učešćem**

## - ZBORNIK RADOVA 2 -

**Čačak, 13 - 14. mart 2020. godine**

# XXV SAVETOVANJE O BIOTEHNOLOGIJI

**sa međunarodnim učešćem**

**-Zbornik radova 2–**


**ORGANIZATOR I IZDAVAČ**

**Univerzitet u Kragujevcu,**
**Agronomski fakultet u Čačku**





**Tehnički urednici**

Dr Pavle Mašković, vanr. prof.; Miloš Petrović, istraživač pripravnik;
dipl. inž. Dušan Marković, asistent

**Tiraž:** 150 primeraka

**Štampa**

*JP SLUŽBENI GLASNIK, Jovana Ristića 1, Beograd*
Godina izdavanja, 2020

# PREDGOVOR

Promene koje se ubrzano dešavaju na globalnom i lokalnom nivou, od naučnih, klimatskih, ekonomskih, pa do političkih, podstiču potrebu da proučimo njihov uticaj na živi svet i na jednu od najvažnijih ljudskih delatnosti - proizvodnju hrane.

Naša poljoprivreda, selo, poljoprivredni proizvođači nisu danas to što su bili pre trideset ili četrdeset godina, srpsko selo se danas više nego ikad ubrzano i u hodu menja. Poljoprivredna nauka mora preuzeti deo odgovornosti u pogledu proizvodnje dovoljne količine kvalitetne hrane za ljudsku ishranu, jer prolaze vremena kada se za svaku lošu žetvu traže opravdanja u klimi.

S′ ciljem da budemo u toku aktuelnih zbivanja, kao i da sami svojim rezultatima utičemo na razvoj poljoprivrede i na delatnosti koje je prate, Agronomski fakultet u Čačku, pored edukacije studenata, redovno, godišnje, organizuje i Savetovanje o biotehnologiji, ovaj put, jubilarno, dvadeset peto po redu.

Osnovni cilj Savetovanja je upoznavanje šire naučne i stručne javnosti sa rezultatima najnovijih naučnih istraživanja, domaćih i inostranih naučnika iz oblasti osnovne poljoprivredne proizvodnje i prerade, kao i zaštite životne sredine. Na taj način Fakultet nastoji da omogući direktan prenos naučnih rezultata široj proizvodnoj praksi, pa pored naučnih radnika, agronoma, tehnologa, na ovogodišnjem Savetovanju biće i značajan broj poljoprivrednih proizvođača, stručnih savetodavaca, nastavnika, itd.

U Zborniku radova jubilarnog XXV Savetovanja o botehnologiji sa međunarodnim učešćem, predstavljeno je ukupno 86 radova iz oblasti Ratarstva, povrtarstva i krmnog bilja, Voćarstva i vinogradarstva, Zootehnike, Zaštite bilja, proizvoda i životne sredine i Prehrambene tehnologije.

Pokrovitelj jubilarnog XXV Savetovanja o biotehnologiji sa međunarodnim učešćem je Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije, a materijalnu i organizacionu podršku su nam pružili grad Čačak, privrednici, dugogodišnji prijatelji Agronomskog fakulteta, kojima se i ovim putem zahvaljujemo.

U Čačku, marta 2020. godine

Programski i Organizacioni odbor
XXV Savetovanja o biotehnologiji

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

63(082)
606:63(082)

**САВЕТОВАЊЕ о биотехнологији са међународним учешћем (25 ; 2020 ; Чачак)**
Zbornik radova. 2 / XXV savetovanje o biotehnologiji sa međunarodnim učešćem, Čačak, 13-14. mart 2020. godine ; [organizator] Univerzitet u Kragujevcu, Agronomski fakultet u Čačku ; [urednik Tomo Milošević]. - Čačak : Univerzitet u Kragujevcu, Agronomski fakultet, 2020 (Beograd : Službeni glasnik). - Str. 331-616 : ilustr. ; 25 cm

Na vrhu nasl. str.: University of Kragujevac, Faculty of Agronomy Cacak. - Radovi na srp. i engl. jeziku. - Tiraž 150. - Bibliografija uz svaki rad.

ISBN 978-86-87611-74-0
ISBN 978-86-87611-75-7 (niz)

а) Пољопривреда -- Зборници б) Биотехнологија -- Зборници

COBISS.SR-ID 283507212