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DRYING CHARACTERISTICS OF ONION PROCESSING WASTE

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Abstract: *Onion processing waste (OPW) was dried in a convective hot-air laboratory scale dryer at 50, 60, 70 and 80ºC. The effect of drying temperature on the drying characteristics and on the total phenolic and total flavonoid content of dried samples was determined. Three mostly used models were applied for fitting the experimental drying curves. The results indicated that the constant rate-drying period was not observed and that the logarithmic model was the most suitable for fitting the experimental drying kinetic data. The drying temperature significantly affected the total phenolic and total flavonoid content of dried OPW. The values of effective diffusivity were calculated and the determined value of activation energy was 28.05 kJ/mol.*

Key words: *onion, waste, drying, kinetics.*

1. Introduction

The development of food products that contain value-added compounds is of great interest nowadays. Dried onion processing waste (OPW) could be potentially used as a value-added low calorie functional food ingredient rich in dietary fibre, total phenols and total flavonoids, with good antioxidant activity [17], [20].

The drying of agricultural materials and foods is one of the important preservation techniques [4], [17]. This process improves food stability and minimizes physical and chemical changes during storage [10]. Convective drying is the most common method used, but air drying has

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disadvantages, such as long drying time, low energy efficiency and product quality changes [5, 6].

Drying kinetics modelling is very important for food drying practice, optimisation and prediction of the drying system. Also, thin-layer drying rates and moisture diffusion parameters of food are essential for an efficient moisture transfer analysis [1], [18].

Several research endeavours have been reported recently the application of convective air drying for different foods [2], [5-16], [18, 19].

Lee and Kim [18] determined the effect of drying temperature on the drying characteristics of onion slices in a hot-air dryer. Mota et al. [19] studied the drying kinetics of hot-air drying of onion at different temperatures and evaluated the influences of the drying process on the chemical composition of onions. Recently, Demiray et al. [6] compared drying characteristics of onion slices dried by conventional and microwave methods.

However, the investigation of the drying characteristics of onion processing waste (OPW) in hot-air drying has not been reported yet. Therefore, the present research was carried out for the determination of the effect of air drying temperature on drying kinetics and on the total phenolic and total flavonoid content of OPW, as well as for fitting the experimental obtained drying curves with three mostly used mathematical models and the calculation of effective diffusivity and activation energy for OPW drying.

2. Materials and Methods

2.1. Raw Material

Fresh brown-skin onion bulbs were purchased from a local market in Plovdiv, Bulgaria and were stored in a refrigerator at 4°C prior to drying experiments [8].

Onion bulbs were hand peeled and the obtained OPW consisted of the apical trimmings of the bulbs and the outer dry and semidry layers were cut into small pieces, washed and dried with filter paper before drying experiments [20].

2.2. Drying Process

The OPW was dried in a convective drier described previously [13]. The experiments were carried out for four temperature modes (50, 60, 70 and 80°C) under the same drying chamber load of 6.6146 kg/m^2. The relative humidity of the air (φ=50%) and air velocity (2.2 m/s) were kept constant during the experiments. The electric transformer sets the power of the electric heater for the respective temperature mode. After 60 s the operating mode is reached and the sample is placed in the drying chamber. From that moment the drying process begins. From the start of drying every 10 min the sample is removed from the drying chamber and weighed for the recording of moisture loss. The drying process continues until the sample mass remains constant for three consecutive measurements.

After each drying experiment, the dried samples were cooled at room temperature and stored in airtight glass jars until future analysis [12].

The total dry matter of the samples was determined by gravimetric method with loss of mass on drying as described previously [13].

The moisture content values for all samples were presented as dimensionless moisture ratio (MR) [18]. The experiments were repeated twice and the average of the MR at each value was used to plot the drying curves [7].

2.3. Determination of the Total Phenolic and Total Flavonoid Content

The extraction of phenols and flavonoids from dried OPW samples was carried out as described previously [20].

The total phenolic content (TPC) of the extract was determined using the Folin–Ciocalteu's reagent. Gallic acid was used as a calibration standard and the results were expressed as mg gallic acid equivalents (GAE) per gram on a dry weight basis (d.w.) [20].

The total flavonoids content (TFC) of the extract was determined by using an $Al(NO_3)_3$ reagent and by measuring the absorbance at 415 nm. The results were presented as mg quercetin equivalents (QE) per gram d.w. [20].

2.4. Drying Curves Modelling

Drying curves were fitted with three mostly used mathematical models namely Lewis, the Henderson and Pabis and the logarithmic models [8]. The MR and drying rate (DR) of OPW were calculated by means of the following equations [8], [10]:

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

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad (2)$$

where:

M, M_0, M_e, M_t and $M_{t+\Delta t}$ are the moisture content at any time of the experiment, initial moisture content, equilibrium moisture content, moisture content at time t and moisture content at time $t+\Delta t$ (kg water/kg dry matter);

t – the drying time [s];

Δt – the time difference [s] [8].

For long drying time, M_e is fairly smaller than M_0 and the equation (1) can be simplified as follow [1, 5, 7]:

$$MR = \frac{M}{M_0} \quad (3)$$

The non-linear regression was performed and the coefficient of determination (R^2), reduced chi-squire (χ^2) and root mean squire error (RMSE) were used to evaluate accuracy of fitted models [8].

2.5. Determination of Effective Moisture Diffusivity and Activation Energy

The effective moisture diffusivity (D_{eff}, m^2/s) was calculated on the basis of Fick's second law by the following relationship [6], [18, 19]:

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

where:

L is the thickness of the slab before the drying step;

t – the drying time [6], [18, 19].

The activation energy (E_a, kJ/mol) was calculated by using the Arhenius relationship plotted between the $\ln(D_{eff})$ and the reciprocial of the absolute air temperature (T, K), as follow [6], [18, 19]:

$$\ln(D_{eff}) = \ln(D_0) - \left(\frac{E_a}{R}\right)\frac{1}{T} \quad (5)$$

where:

D_0 is the pre-exponential factor of the Arhenius equation (m^2/s);
R – the universal gas constant (8.3143 kJ/mol.K) [6], [18, 19].

3. Results and Discussions

3.1. Effect of Drying Temperature on Drying Kinetics

Figure 1 represents obtained drying curves at different air temperatures and fitting the experimental points to the Logarithmic model.

Results indicated that drying temperature strongly affected the drying time. Drying time at 50°C (180 min) was the highest and at 80°C the lowest (90 min) and the obtained reduction in drying time reached 50%. The MR of OPW decreased exponentially with the drying time which is typically reported for food stuffs [18]. Data from Figure 1 indicated that the constant rate-drying period was not observed for all samples, as reported similarly by other studies [6], [8, 9], [11, 18].

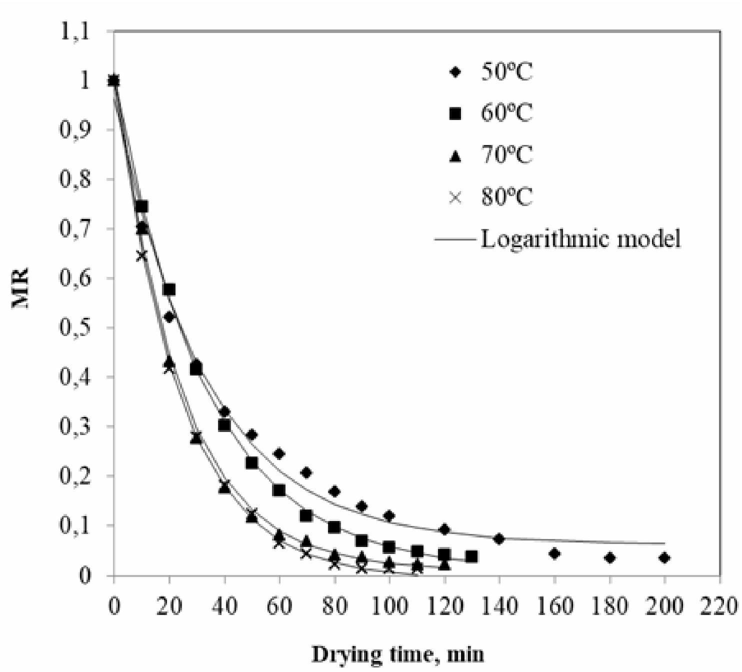

Fig. 1. *Drying curves at different temperatures and fitted Logarithmic model*

The relationship between DR and MR is presented in Figure 2. The results indicated that the increase of drying temperature led to an increase of DR and DR decreases continuously with a decrease of MR, which is in agreement with other studies [8], [18].

The results from drying curves modelling are presented in Table 1.

The data indicated that all investigated models satisfactorily described air-drying of OPW, but the logarithmic model gave the highest R^2 values and the lowest χ^2 and RMSE values in the investigated temperature range (Table 1 and Figure 1). Similar results were reported for hot-air drying of onion slices [18] and white mulberry [7].

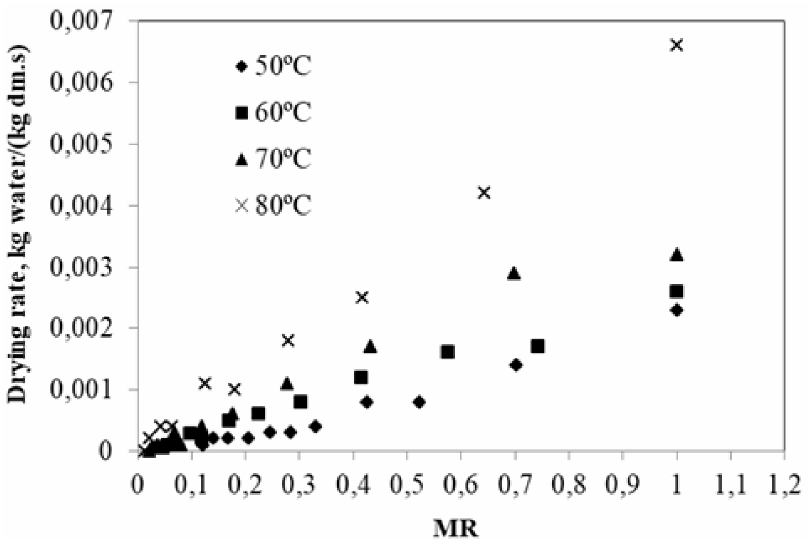

Fig. 2. *Drying rates vs MR at different temperatures*

Mathematical models characteristics for drying of OPW Table 1

Models [8]	Temperature [°C]	Model parameters	R^2	χ^2	RMSE
Lewis $MR = \exp(-kt)$	50	k = 0.0004	0.9747	0.00210	0.0432
	60	k = 0.0005	0.9991	0.00010	0.0108
	70	k = 0.0007	0.9977	0.00030	0.0151
	80	k = 0.0007	0.9995	0.00010	0.0094
Henderson and Pabis $MR = a.\exp(-kt)$	50	a = 0.9295 k = 0.0004	0.9817	0.00140	0.0356
	60	a = 1.0024 k = 0.0005	0.9991	0.00010	0.0104
	70	a = 1.0119 k = 0.0007	0.9979	0.00020	0.0141
	80	a = 0.9987 k = 0.0007	0.9995	0.00010	0.0092
Logarithmic $MR = a.\exp(-kt) + c$	50	a = 0.8998 k = 0.0005 c = 0.0628	0.9919	0.00070	0.0245
	60	a = 0.9973 k = 0.0005 c = 0.0086	0.9993	0.00008	0.0078
	70	a = 1.0054 k = 0.0007 c = 0.0102	0.9980	0.00020	0.0135
	80	a = 1.0046 k = 0.0007 c = 0.0086	0.9996	0.00006	0.0067

3.2. Effect of Drying Temperature on the Total Phenolic and Total Flavonoid Contents of Dried Opw

The results for the effect of drying temperature on the total phenolic and total flavonoid contents of dried OPW are presented in Table 2.

Table 2

Total phenolic (TPC) and total flavonoid (TFC) contents of dried OPW

Temperature [°C]	TPC [mg GAE/g]	TFC [mgTQ/g]
50	12.01 ± 0.07^{a}	8.01 ± 0.06^{a}
60	11.64 ± 0.03^{b}	7.87 ± 0.02^{b}
70	11.75 ± 0.04^{b}	7.33 ± 0.02^{c}
80	11.36 ± 0.09^{c}	7.30 ± 0.01^{c}

Note: Mean ± SD of three independent measurements.Values within each column followed by different letters (a to c) are significantly different ($p < 0.05$).

An increase in drying temperature results in the reduction of the TPC and TFC of dried OPW.

The losses of the TPC and TFC could be explained by the possible degradation of phenolic and flavonoid compounds during drying, because of oxidation, the Maillard reaction, binding with other compounds or with the modification of the chemical structure following heat treatment. Additionally, a decrease in flavonoid content may be due to the oxidation or polymerization occurring during drying. These reductions are significantly ($p < 0.05$) related to drying temperature and duration [3], [15]. The results indicated that the drying temperature of 60°C could be suitable for the drying of OPW from the engineering point of view. The reductions obtained for TPC and TFC at 60°C were 3.1% and 1.7%, respectively, as compared to drying at 50°C. However, a significant reduction of drying time by 50 min was obtained when the temperature was increased from 50 to 60°C, which affects the energy efficiency of drying.

3.3. Effective Diffusivity and Activation Energy

The calculated values of D_{eff} for different temperatures are shown in Table 3. Results indicated that D_{eff} values increased with increases of drying temperature, as reported by other studies [6], [18, 19]. Values of D_{eff} for drying of OPW have not been found in the literature. Similarly, reported values for dried onion slices were in the ranges of 1.345×10^{-8} to 2.658×10^{-8} [18] and 3.49×10^{-8} to 9.44×10^{-8} [6] for temperature intervals from 50 to 70°C.

Table 3

Values of D_{eff} for the drying of OPW at different temperatures

Temperature [°C]	D_{eff} [m^2/s]
50	1.90×10^{-8}
60	2.54×10^{-8}
70	3.80×10^{-8}
80	4.44×10^{-8}

The calculated D_{eff} was plotted as a function of the absolute air temperature [6] and the results are presented in Figure 3.

The value of E_a calculated by equation (5) was 28.05 kJ/mol and was within the general range of 12.7 to 110 kJ/mol for different food materials [10]. Mota et al. [19] reported similar values of E_a (26.4 kJ/mol) for the drying of onion slices.

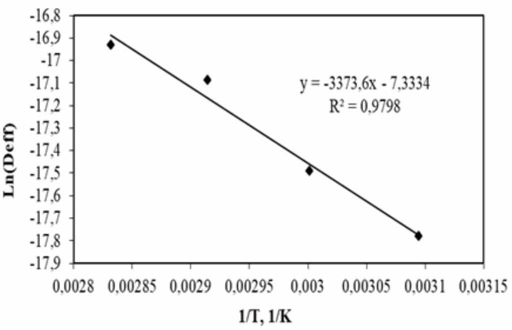

Fig. 3. *Arhenius relationship between D_{eff} and absolute air temperature*

4. Conclusions

In the present study, convective hot-air drying of OPW was applied at four different inlet air temperatures. Results indicated that the increase in drying temperature led to the increase of drying rate and to a drying rate decrease with a decrease of moisture ratio. The drying temperature significantly affected the TPC and TFC of dried OPW. Three mostly used models were applied to describe the drying kinetics of OPW. The logarithmic model gave the highest coefficients of determination and lowest values of reduced chi-squire and RMSE for all investigated samples. Calculated values of D_{eff} were in the range from 1.90×10^{-8} m^2/s at 50°C to 4.44×10^{-8} m^2/s at 80°C and the determined Ea was 28.05 kJ/mol.

References

1. Ashtiani S.-H., Salarikia A., Golzarian M., 2017. Analyzing drying characteristics and modelling of thin layer of peppermint leaves under hot-air and infrared treatments. In: Information Processing in Agriculture, vol. 4(2), pp. 128-139.
2. Ben Haj Said L., Najjaa H., Neffati M. et al., 2015. Thin layer convective air drying of wild edible plant *Allium roseum* leaves: Experimental kinetics, modelling and quality. In: Journal of Food Science and Technology, vol. 52(6), pp. 3739-3749.
3. Ben Haj Said L., Najjaa H., Neffati M. et al., 2013. Color, phenolic and antioxidant characteristic changes of Allium Roseum leaves during drying. In: Journal of Food Quality, vol. 36, pp. 403-410.
4. Brătucu Gh., Marin A., Păunescu D., 2016. Experimental researches concerning the optimization of the duration of the drying process for the apples conservation. In: Bulletin of the Transilvania University of Braşov – Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 9(58), no. 1, pp. 59-68.
5. Darvishi H., Asl A.R., Asghari A. et al., 2014. Study of the drying kinetics of pepper. In: Journal of the Saudi Society of Agricultural Sciences, vol. 13(2), pp. 130-138.
6. Demiray E., Seker A., Tulek Y., 2017. Drying kinetics of onion *(Allium cepa* L.) slices with convective and microwave drying. In: Heat and Mass Transfer, vol. 53(5), pp. 1817-1827.
7. Doymaz I., 2004. Drying kinetics of white mulberry. In: Journal of Food Engineering, vol. 61(3), pp. 341-346.
8. Doymaz I., 2006. Thin-layer behaviour of mint leaves. In: Journal of Food Engineering, vol. 74(3), pp. 370-375.
9. Doymaz I., 2009. Thin-layer drying of spinach leaves in a convective dryer. In: Journal of Food Processing Engineering, vol. 32(1), pp. 112-125.
10. Doymaz I., 2012. Evaluation of some thin-layer drying models of persimmon slices (*Diospyros kaki* L.). In: Energy Conversion and

Management, vol. 56, pp. 199-205.
11. Doymaz I., Gorel O., Akgun N., 2004. Drying characteristics of the solid by-product of olive oil extraction. In: Biosystems Engineering, vol. 88(2), pp. 213-219.
12. Doymaz I., Tugrul N., Pala M., 2006. Drying characteristics of dill and parsley leaves. In: Journal of Food Engineering, vol. 77(3), pp. 559-565.
13. Georgieva M.G., Tashev At.I., Atanasov D.G. et al., 2018. Energy efficiency of impulse drying regimes of beetroot. In: Bulgarian Chemical Communication, vol. 50, issue G., pp. 230-235.
14. Guiné R., Pinho S., Barroca M., 2011. Study of the convective drying of pumpkin (*Cucurbita maxima*). In: Food and Biproducts Processing, vol. 89(4), pp. 422-428.
15. Harborne N., Marete E., Jacquier J.C. et al., 2009. Effect of drying methods on the phenolic constituents of meadowsweet (*Filipendula ulmaria*) and willow (*Salix alba*). In: LWT – Food Science and Technology, vol. 42(9), pp. 1468-1473.
16. Kaya A., Aydin O., 2009. An experimental study on drying kinetics of some herbal leaves. In: Energy Conversation and Management, vol. 50(1), pp. 118-124.
17. Kiryakov I., Prokopov T., Georgieva M. et al., 2018. Equilibrium moisture content of onion processing waste powder. In: Bulletin of the Transilvania University of Brasov - Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 11(60), no. 2, pp. 115-120.
18. Lee J., Kim H., 2008. Drying kinetics of onion slices in a hot-air dryer. In: Journal of Food Science and Nutrition, vol. 13(3), pp. 225-230.
19. Mota C., Luciano C., Dias A. et al., 2010. Convective drying of onion: Kinetics and nutritional evaluation. In: Food and Bioproducts Processing, vol. 88(2-3), pp. 115-123.
20. Prokopov T., Slavov A., Petkova N. et al., 2018. Study of onion processing waste powder for potential use in food sector. In: Acta Alimentaria, vol. 47(2), pp. 181-188.