CI&CEQ
Chemical Industry & Chemical Engineering Quarterly

Available on line at
Association of the Chemical Engineers of Serbia *AChE*
www.ache.org.rs/CICEQ

Chem. Ind. Chem. Eng. Q. 26 (2) 203–212 (2020) CI&CEQ

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SCIENTIFIC PAPER

UDC 635.64:66.047.3.085.1:66.012.3

MICROWAVE AND INFRARED DRYING KINETICS AND ENERGY CONSUMPTION OF CHERRY TOMATOES

Article Highlights

- The effect of MW and IR power on drying kinetics of cherry tomatoes is investigated
- Experimental moisture ratios are fitted to seven widely used thin-layer models
- Weibull and Aghbashlo *et al.* best fit the data for MW and IR drying of cherry tomatoes
- D_{eff} for MW and IR are calculated: 5.46×10^{-8}-4.24×10^{-7} m^2/s and 7.33×10^{-9}-8.24×10^{-9} m^2/s
- MW and IR activation energies are found as 9.4654 and 0.3162 kW/kg, respectively

Abstract

In this study, the effect of different microwave and infrared power levels on drying kinetics of cherry tomatoes is investigated. Drying experiments are carried out with the power levels of 90, 180, 270 and 360 W (5.625, 11.250, 16.875 and 22.500 W/g as power density) in microwave studies and 74, 83 and 104 W (0.871, 0.976 and 1.224 W/g as power density) in infrared studies. The obtained experimental moisture ratios are fitted to seven different widely used thin-layer models and the results showed that Weibull and Aghbashlo et al. models best fit the data for microwave and infrared drying of cherry tomatoes. The effective moisture diffusivities for microwave and infrared drying studies are calculated between 5.46×10^{-8} and 4.24×10^{-7} m^2/s and 7.33×10^{-9}--8.24×10^{-9} m^2/s, respectively. Additionally, microwave and infrared activation energies are found to be 9.4654 and 0.3162 kW/kg, respectively.

Keywords: cherry tomato, drying kinetics, infrared drying, microwave drying, effective moisture diffusivity, activation energy.

Tomato (*Lycopersicon esculentum*) is the second most important vegetable cultivated throughout the world with production at about 182 million tons and Turkey is the fourth biggest producer after China, India and USA at about 105.6 million tons [1,2]. Cherry tomatoes (*Lycopersicon esculentum* var. *Cerasiforme*) is a kind of a small tomato used in salad dressing. Since tomatoes deteriorate within 2-3 weeks after harvesting, it is very important to improve their shelf life and make the fruit available when not in season; for this reason, tomatoes are often dried and sold in a dehydrated form [3].

The drying process has been used for a long time in the food processing industries in order to increase the final product's long-term preservation. Moisture content in food products leads to decay and spoilage due to its microbiological activity. The simplest method of drying is the hot-air drying method, which has some disadvantages such as lower energy efficiency and long drying times [4-6]. For the last twenty years, microwave drying has been an interest among researchers. This new-generation drying method is used due to the rapid absorption of heat by water inside the food product, which causes fast removal of water molecules, thus leading to a decrease of drying time and energy. Another efficient method is the infrared drying method. In this method, high heat transfer coefficients and short processing times are the advantages, compared to hot-air drying

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Paper received: 16 September, 2019
Paper revised: 13 November, 2019
Paper accepted: 29 November, 2019

https://doi.org/10.2298/CICEQ190916039K

[5]. Infrared radiation creates internal heating with molecular vibration of the material thus generating heat [7].

In literature, several vegetables and fruits were studied using microwave drying methods, such as apples [8], blueberries [9], carrot slices [10], cranberries [11], garlic [12], green beans [6], green peas [13], mushrooms [14], potatoes [15] and tomato pomace [16]. Likewise, banana [4], carrot [17], paddy [18], onion [19] are the several examples of infrared dying studies that can be found in literature. Also, Heredia *et al.* [20,21] studied the combination of different dehydration techniques on cherry tomatoes with osmotic solution.

As it is seen from the literature, despite the studies about tomatoes, the microwave and infrared drying kinetics of cherry tomatoes without pre-treatment were not studied. In this study, the thin-layer behaviour of cherry tomatoes is investigated using both the drying methods of microwave and infrared. For the mathematical modelling, seven widely used thin layer models that can be found in literature are applied to experimental moisture ratios. Also, the effective moisture diffusivities and activation energies obtained from two different drying methods are calculated.

EXPERIMENTAL

Materials preparation and determination of the moisture content

Cherry tomatoes were obtained from a local supermarket in İstanbul. All samples of cherry tomatoes were selected from round ones and cleaned with tap water to remove the dust and unwanted materials that will affect the experiments; the surface moisture was removed using a paper towel. After the cleaning process, the cherry tomatoes were cut into halves with the approximate diameter of 36.6 mm.

Initial moisture contents of the cherry tomatoes were determined using a method of AOAC [22] and found to be 15.29 kg water/kg dry matter (93.86% wet base), while Fernandes *et al.* and An *et al.* reported the initial moisture content of the cherry tomatoes to be 92.4±0.5 kg water/100 kg fresh fruit (wet basis) [23] and 94.43±0.35% wet basis [24], respectively. For the method, Ecocell LSIS-B2V/EC55 model incubator (MMM Medcenter Einrichtungen GmbH, Planegg, Germany) was used. Four parallel experiments were conducted and the average values of the moisture contents were calculated.

Drying equipment and procedures

For the microwave drying experiments, Bosch HMT72G420 model microwave oven (Robert Bosch Hausgerate GmbH, Munich, Germany) was used which operates at 2450 MHz and has a maximum generated output power of 800 W. The device delivers the set microwave power in a particular time of process. The dimensions of the microwave oven are 530, 500 and 322 mm and at the base of the oven a rotating glass plate with 300 mm diameter is present. 16±0.5 g cherry tomatoes were weighted using Ohaus PA214C digital balance, which has an accuracy of 0.001 g (Ohaus Corporation, NY, USA). Then the drying process was carried out at microwave powers of 90, 180, 270 and 360 W (5.625, 11.250, 16.875 and 22.500 W/g as power density). On the other hand, infrared drying experiments were carried out in a moisture analyzer (Model no: 26680, Snijders Moisture Balance, Snijders b.v., Tilburg, Holland) with one 250 W generated power halogen lamp (Near-IR). 85±1 g cherry tomatoes were weighed then the drying process was carried out at infrared powers of 74, 88 and 104 W (0.871, 0.976 and 1.224 W/g as power density), where the power levels were measured with a digital energy meter (PeakTech 9035, Germany) and the level of the power was set from the equipment's control unit. Drying was finished when the moisture content of cherry tomatoes was approximately 0.3 kg water/kg dry matter, while An *et al.* terminated the drying procedure at the moisture level of 25 g/100 g dry matter [24]. All of the weighing process was completed in 10 s, as given in the literature [25].

Mathematical modelling

Cherry tomatoes' moisture content (M), drying rate (DR) and moisture ratio (MR) were calculated using Eqs. (1)-(3):

$$M = \frac{m_w}{m_d} \tag{1}$$

where M, m_w and m_d are the moisture content (kg water/kg dry matter), water content (g) and dry matter content (g), respectively.

$$DR = \frac{M_{t+\mathrm{d}t} - M_t}{\mathrm{d}t} \tag{2}$$

where DR, $M_{t+\mathrm{d}t}$ and t are the drying rate (kg water/(kg dry matter min)), moisture content at $t + \mathrm{d}t$ (kg water/kg dry matter) and drying time (min), respectively.

$$MR = \frac{M_t - M_e}{M_i - M_e} \tag{3}$$

where MR is the moisture ratio (dimensionless), M_t, M_e and M_i are the moisture content at selected time, at equilibrium and the initial value in kg water/kg dry matter, respectively. Especially in microwave and infrared drying methods, M_e has a very small value compared to M_t, and M_i, so M_e values are neglected in the calculations. The drying curves were analysed with 15 different mathematical models, which are widely used in the literature for food products.

Statistical analysis

Statistica 8.0 computer programme (StatSoft Inc., Tulsa, OK, USA) was used for regression analysis. Non-linear regression procedure based on the Lavenberg-Marquardt algorithm was used in estimating the model parameters. From the predicted, the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error ($RMSE$) are calculated. Among the fifteen drying models, the best seven models that gave the higher R^2 values were evaluated and given in Table 1.

In the literature, higher R^2 values and lower χ^2 and $RMSE$ values were accepted as better results [32-35]. R^2, χ^2 and $RMSE$ equations are given in Eqs. (4)–(6), respectively:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{\exp,i} - \left(\frac{1}{n}\right)\sum_{i=1}^{N} MR_{\exp,i}\right)} \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (5)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right)^{1/2} \quad (6)$$

where MR_{exp} and MR_{pre} represent moisture ratio values of the experimental and predicted, respectively. N and z are the total number of experiments and number of constants in the model, respectively.

Determination of effective moisture diffusivity

The values of effective moisture diffusivity values can be calculated according to Fick's second law of diffusion in the falling-rate period and the equation can be expressed as [36]:

$$MR = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2} exp\left(-\frac{\pi^2 D_{eff}}{4L^2} t\right) \quad (7)$$

To obtain a straight-line solution n is taken as 1 and Eq. (8) is simplified and given below [36]:

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

where D_{eff}, L and t are the effective moisture diffusivity (m^2/s), the half-thickness of the slab (m) and the drying time (s), respectively. D_{eff} can be calculated from the plot of *ln(MR) versus t*.

Determination of activation energy

The dependence of the effective moisture diffusivity on temperature is described by a derived modified form of the Arrhenius equation that shows the relationship between the effective diffusivity and the infrared and microwave power level to sample weight, Eq. (9) [37]:

$$D_{eff} = D_0 \exp\left(-\frac{E_a m}{P}\right) \quad (9)$$

where m, P, *and* E_a are the sample weight (kg), microwave power (W) and activation energy (W/kg) respectively.

Table 1. Models used for fitting the experimental data

Model	Equation	Reference
Aghbashlo *et al.*	$MR = \exp\left(-\frac{k_1 t}{1 + k_2 t}\right)$	[26]
Henderson and Pabis	$MR = a\exp(-kt)$	[27]
Jena	$MR = a\exp\left(-kt + bt^{0.5}\right) + c$	[28]
Logaritmic	$MR = a\exp(-kt) + c$	[6]
Parabolic	$MR = a + bt + ct^2$	[29]
Wang and Singh	$MR = 1 + at + bt^2$	[30]
Weibull	$MR = \exp\left(-\left(\frac{t}{b}\right)^a\right)$	[31]

Determination of energy consumption

The energy needed to evaporate a mass unit of water from the products was calculated using Eq. (10):

$$Q = Pt \quad (10)$$

where Q, P and t are the energy consumption (kW h), microwave power (kW) and drying time (h), respectively.

RESULTS AND DISCUSSION

Drying curves

Figure 1 shows the effect of microwave and infrared power levels on the drying of cherry tomatoes. Drying curves are similar to food products including fruit and vegetable drying studies.

In the microwave studies, the drying times needed for reaching the final moisture content are found as 68, 34, 12 and 7 min for the microwave power levels 90, 180, 270 and 360 W (5.625, 11.250, 16.875 and 22.500 W/g), respectively. On the other hand, in the infrared studies the drying times needed for reaching the final moisture content are found as 510, 390 and 330 min for the infrared power levels 74, 88 and 104 W (0.871, 0.976 and 1.224 W/g), respectively. In the literature, it is explained that the higher heat absorption leads to higher product temperature, higher mass transfer driving force, faster drying rates and shorter drying times [2,38,39]. Hence, it is seen from the results that higher power, both microwave and infrared, leads to higher heat absorption.

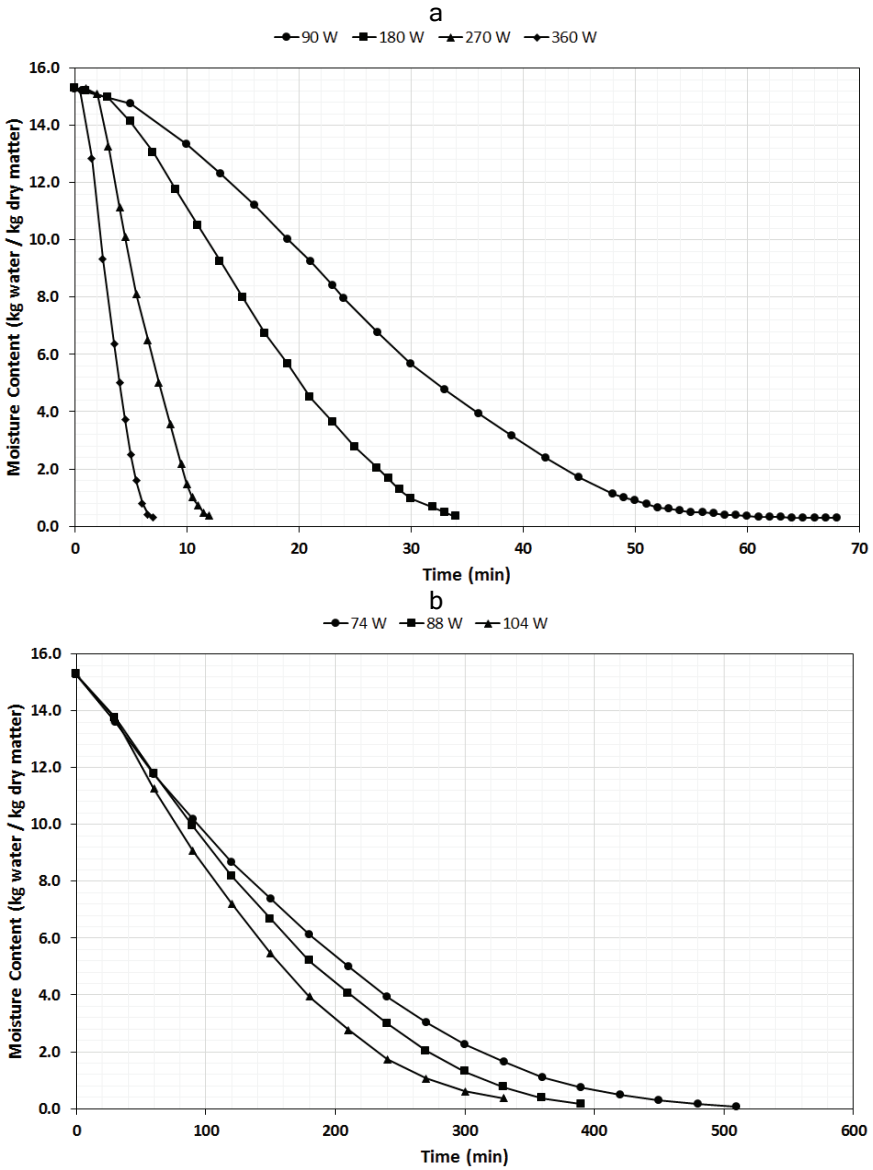


Figure 1. Drying curves of cherry tomatoes at different power levels: a) MW; b) IR.

Drying rate curves

In the literature, it has been explained that the moisture transfer from the solid matter is explained using Fick's second law and the drying of food products generally follows the falling-rate period [40-42]. Drying rate curves of cherry tomatoes at different MW and IR power levels are given in Figure 2. Generally, it is seen that high power leads to the increase in the drying rates in both of the drying methods.

In the microwave studies, the rising-rate period is seen from the initial content of 15.29 kg water/kg dry matter to 7.97, 11.75, 11.13 and 9.32 kg water/kg dry matter for the microwave power levels of 90, 180, 270 and 360 W (5.625, 11.250, 16.875 and 22.500 W/g), respectively. Below the above-mentioned moisture contents in 270 and 360 W, a falling-rate period is seen. At the microwave power level of 90 W, a constant rate period is seen between the moisture contents of 7.97 kg water/kg dry matter and 1.26 kg water/kg dry matter and a falling rate period is seen at the lower moisture content of 1.26 kg water/kg dry matter. Similarly, in the microwave power level of 180 W, a constant rate period is seen between the moisture contents of 11.75 kg water/kg dry matter and 4.48 kg water/kg dry matter and a falling rate period is seen at the lower moisture content of 4.48 kg water/kg dry matter.

In the infrared studies, the constant-rate period is not seen and the rising-rate period is seen from the moisture content of 15.29 kg water/kg dry matter to 11.76, 11.79 and 11.25 kg water/kg dry matter at

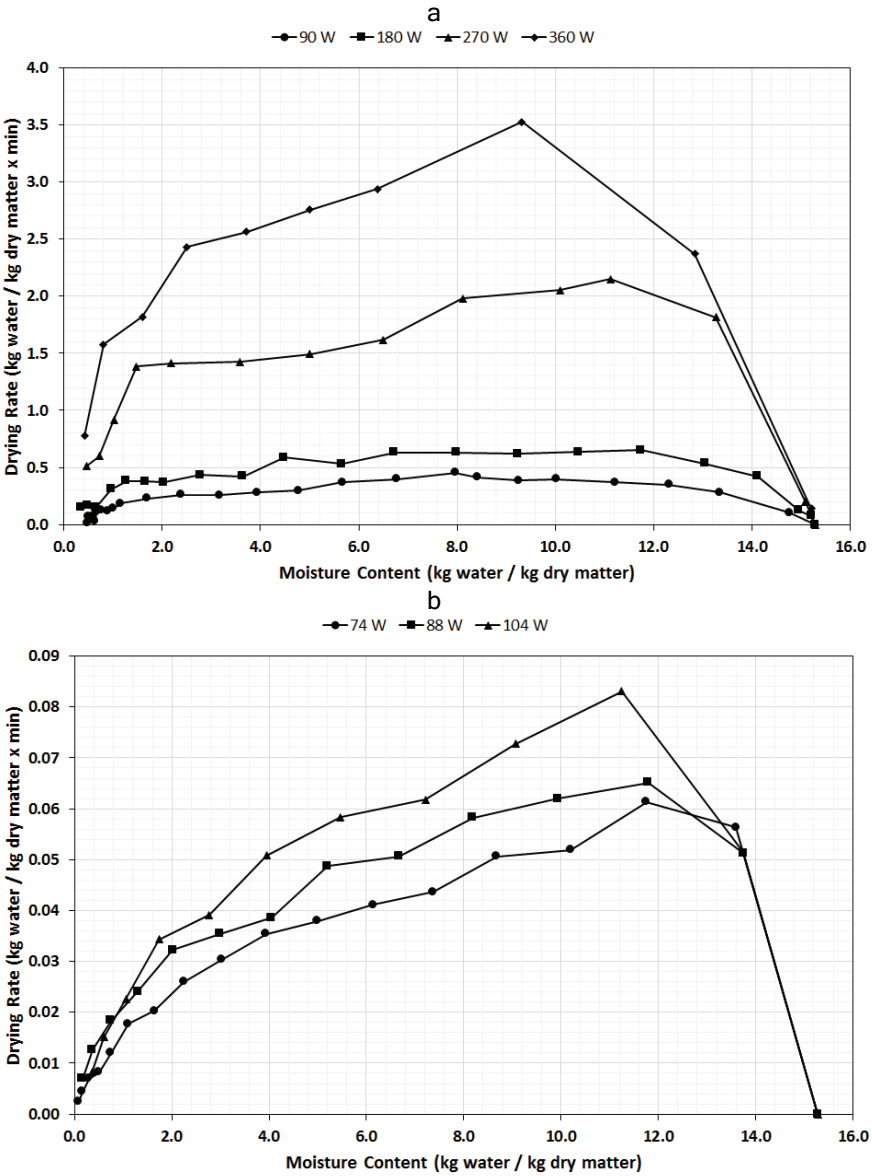


Figure 2. Drying rate curves of cherry tomatoes at different power levels: a) MW; b) IR.

infrared power levels of 74, 88 and 104 W (0.871, 0.976 and 1.224 W/g), respectively. Below the mentioned moisture contents, a falling-rate period is seen at the infrared power levels.

Evaluation of models

The best model, among the Aghbashlo *et al.*, Henderson and Pabis, Jena, logarithmic, parabolic, Wang and Singh and Weibull models, was selected based on the highest R^2 and lowest χ^2 and *RMSE* values. In Table 2, all statistical results obtained from evaluation of the models and calculated model constants are given. From the results obtained, the lowest R^2 values of 0.9651 and 0.9871 were determined for the microwave and infrared studies which means that the predicted data were in good agreement with the experimental data. This indicates that all selected models successfully described the relation between *MR* and the drying time. For the microwave studies it is seen that the calculated R^2, χ^2 and *RMSE* values were in ranges of 0.9651–0.9997, 0.0001–0.0069 and 0.0082–0.0905, respectively. The highest R^2 and lowest χ^2 and *RMSE* values are observed for the Weibull model at 90 W power, and the lowest R^2 and highest χ^2 and *RMSE* values are seen in the Henderson and Pabis model for 90 W power. Among the seven thin-layer models, the Weibull model best fits the experimental *MR* for all microwave power levels.

Table 2. Estimated coefficients and statistical data obtained from different drying models

Model	Parameter	Method						
		Microwave				Infrared		
		Power (W)						
		90	180	270	360	74	88	104
		Power density (W/g)						
		5.625	11.250	16.875	22.250	0.871	0.976	1.224
Aghbashlo *et al.*	k_1	0.0173	0.0260	0.0870	0.1311	0.0040	0.0041	0.0047
	k_2	-0.0142	-0.0246	-0.0708	-0.1270	-0.0012	-0.0017	-0.0020
	R^2	0.9971	0.9970	0.9960	0.9970	0.9999	0.9998	0.9992
	χ^2	0.0006	0.0008	0.0011	0.0005	0.00001	0.00005	0.0002
	RMSE	0.0237	0.0275	0.0312	0.0218	0.0026	0.0067	0.0131
Henderson and Pabis	*a*	1.2355	1.1615	1.1679	1.1332	1.0703	1.0850	1.0863
	k	0.0442	0.0641	0.2028	0.3300	0.0060	0.0068	0.0078
	R^2	0.9651	0.9667	0.9684	0.9673	0.9910	0.9871	0.9870
	χ^2	0.0069	0.0905	0.0087	0.0098	0.0020	0.0020	0.0033
	RMSE	0.0810	0.0905	0.0873	0.0905	0.0423	0.0521	0.0526
Jena	*a*	0.3357	0.1912	0.2133	0.2390	0.1650	0.2631	0.1399
	k	0.0787	0.1160	0.3550	0.5790	0.0081	0.0098	0.0116
	b	0.2429	0.2757	0.4438	0.5651	0.0357	0.0464	0.0530
	c	1.0282	1.5664	1.5129	1.3961	1.7803	1.3175	1.9559
	R^2	0.9907	0.9896	0.9917	0.9900	0.9961	0.9955	0.9970
	χ^2	0.0020	0.0273	0.0027	0.0038	0.0010	0.0013	0.0010
	RMSE	0.0422	0.0510	0.0450	0.0504	0.0279	0.0306	0.0253
Logaritmic	*a*	1.4721	2.8606	1.8525	2.2280	1.1910	1.3393	1.3313
	k	0.0236	0.0143	0.0771	0.0987	0.0043	0.0040	0.0047
	c	-0.3426	-1.7877	-0.7690	-1.1578	-0.1633	-0.3058	-0.2906
	R^2	0.9890	0.9952	0.9932	0.9932	0.9985	0.9985	0.9975
	χ^2	0.0458	0.0014	0.0021	0.0023	0.0004	0.0004	0.0007
	RMSE	0.0023	0.0348	0.0408	0.0414	0.0173	0.0181	0.0233
Parabolic	*a*	1.1346	1.0762	1.0882	1.0743	1.0031	1.0242	1.0336
	b	-0.0322	-0.0411	-0.1405	-0.2193	-0.0041	-0.0048	-0.0057
	c	0.0002	0.0003	0.0040	0.0088	0.000004	0.000005	0.000008
	R^2	0.9936	0.9954	0.9943	0.9939	0.9999	0.9996	0.9990
	χ^2	0.0349	0.0013	0.0017	0.0021	0.00002	0.00011	0.00028
	RMSE	0.0013	0.0375	0.0374	0.0393	0.0037	0.0093	0.0146

Table 2. Continued

Model	Parameter	Method						
		Microwave				Infrared		
		Power (W)						
		90	180	270	360	74	88	104
		Power density (W/g)						
		5.625	11.250	16.875	22.250	0.871	0.976	1.224
Wang and Singh	*a*	-0.0250	-0.0326	-0.1127	-0.1817	-0.0041	-0.0045	-0.0053
	b	0.00014	0.00006	0.0022	0.0046	0.000004	0.000005	0.000007
	R^2	0.9871	0.9921	0.9904	0.9906	0.9999	0.9992	0.9982
	χ^2	0.0026	0.0023	0.0027	0.0029	0.00002	0.0002	0.0005
	RMSE	0.0496	0.0442	0.0485	0.0489	0.0039	0.0131	0.0196
Weibull	*b*	29.99	18.64	5.983	3.6953	184.51	166.04	143.22
	a	1.9141	1.9400	1.8658	1.9915	1.3254	1.4271	1.4477
	R^2	0.9997	0.9995	0.9988	0.9993	0.9986	0.9988	0.9995
	χ^2	0.0001	0.0001	0.0003	0.0002	0.0003	0.0003	0.0001
	RMSE	0.0082	0.0111	0.0169	0.0118	0.0167	0.0157	0.0106

For the infrared studies, calculated R^2, χ^2 and *RMSE* values were in ranges of 0.9870–0.9999, 0.000004–0.0033 and 0.0026–0.0526, respectively. The highest R^2 and lowest χ^2 and *RMSE* values are observed for the Aghbashlo *et al.* model at 74 W power, and the lowest R^2 and highest χ^2 and *RMSE* values are seen in the Henderson and Pabis model at 104 W power. Among the seven thin-layer models, the Aghbashlo *et al.* model best fits the experimental *MR* for all infrared power levels.

Figure 3 shows both the microwave and infrared predicted MR *versus* experimental MR plots, and it is seen that the plotted data points follow a nearly 45° straight line, and it can be concluded that there is a good agreement between the experimental and the predicted MR values.

Effective moisture diffusivities

The logarithmic values of the *MR* are plotted *versus* drying time in order to calculate the effective moisture diffusivities. From the slope of the plots, D_{eff} values were calculated and ranged from 5.46×10^{-8} to 4.24×10^{-7} m^2/s for microwave and from 7.33×10^{-9} to 8.24×10^{-9} m^2/s for infrared drying studies. As it is seen with increasing microwave and infrared power levels, the values of D_{eff} is greatly increased. This increase in D_{eff} can be explained by the rapid rise in the temperature of tomato slices, thus the increase of vapour pressure, leading to faster drying. The highest D_{eff} values were found at 360 W in the microwave drying studies and 104 W in the infrared drying studies. Likewise, the lowest D_{eff} values were found at 90 W in the microwave drying studies and 74 W in the infrared drying studies. The calculated values of D_{eff} were consistent with the values given in literature, where Abano *et al.* (2012) [2] found the values to be between 7.22×10^{-9} and 25.19×10^{-9} m^2/s for tomato slices by using combined microwave-vacuum drying, Bagheri *et al.* (2013) [43] found values between 3.42×10^{-9} and 8.69×10^{-9} m^2/s for tomato slices by using open sun-drying and Bennamoun *et al.* (2015) [44] found values between 3×10^{-10} and 5×10^{-10} m^2/s for cherry tomatoes by using convective drying.

Activation energies

In the plot of ln D_{eff} against weight/power levels of both microwave and infrared, the slope of the line is equal to $-E_a$ and the intercept equals to ln(D_0). Thus, D_{eff} equations can be written as in Eqs. (11) and (12):

$$D_{eff} = 3.57\times10^{-7}\exp\left(-\frac{9463.4m}{P}\right) \quad (11)$$

($R^2 = 0.7616$), for MW

$$D_{eff} = 1.07\times10^{-8}\exp\left(-\frac{316.24\times m}{P}\right) \quad (12)$$

($R^2 = 0.8859$), for IR

The estimated values of D_0 and E_a are 3.57×10^{-7} m^2/s and 9.4654 kW/kg for microwave and 1.07×10^{-8} m^2/s and 0.3162 kW/kg for infrared drying studies.

Energy consumptions

The energy consumptions at different microwave and infrared power levels for cherry tomatoes are calculated and were found to be 0.1035, 0.1020, 0.0540 and 0.0420 kW h at 90, 180, 270 and 360 W,

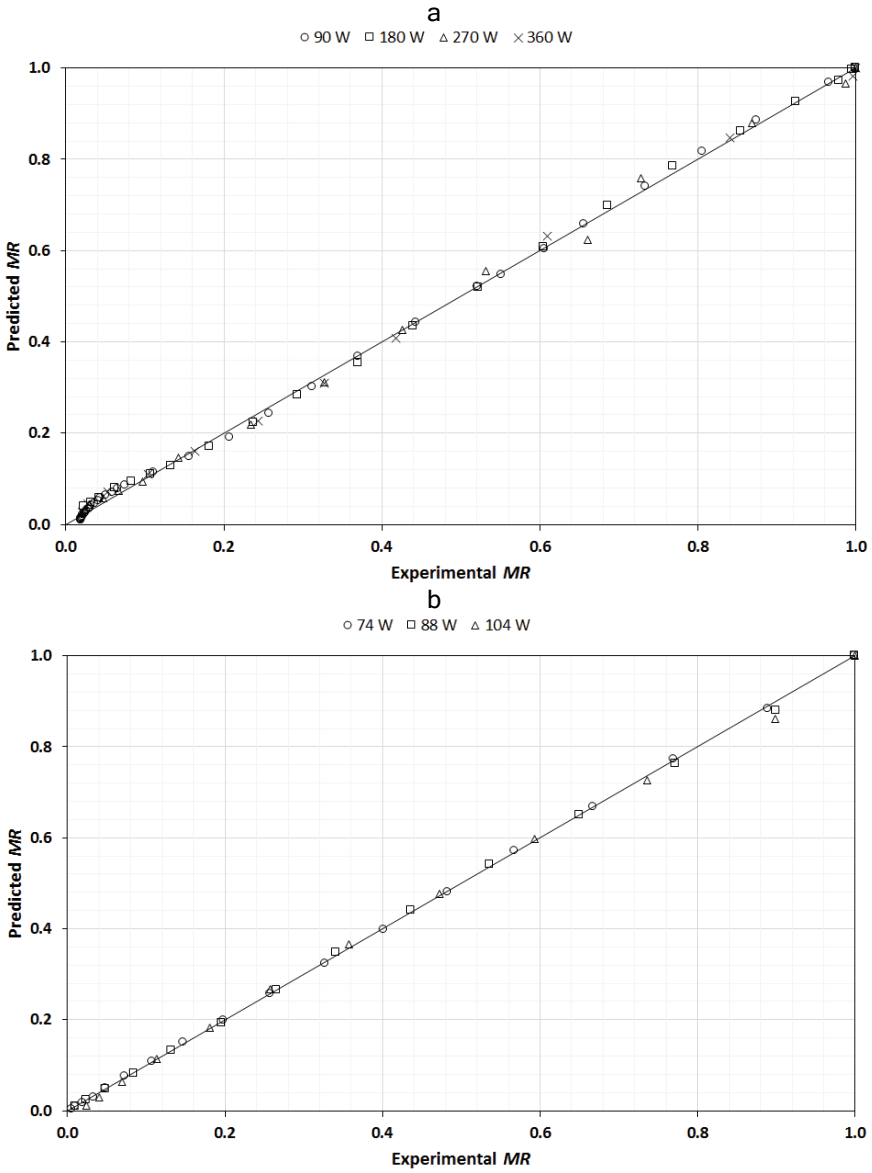


Figure 3. Comparison of experimental and predicted moisture ratios for cherry tomatoes obtained from: a) MR drying studies (Weibull model); b) IR drying studies (Aghbashlo et al. model).

respectively, for microwave drying studies, and 0.6290, 0.5720 and 0.5720 kW h at 74, 88 and 104 W, respectively, for infrared drying studies.

CONCLUSIONS

In this study, using the methods of both microwave and infrared, the drying characteristics of cherry tomatoes were investigated. Rising-rate, constant--rate and falling-rate periods are observed in the microwave drying process and rising-rate and falling-rate periods are observed in the infrared drying process. The drying times decreased with increasing both microwave and infrared power levels. Among the studied seven different thin-layer drying models, the Weibull and Aghbashlo *et al.* models best fit the with the experimental data for microwave and infrared studies, respectively. The effective moisture diffusivities are found to be between 5.46×10^{-8} and 4.24×10^{-7} m^2/s for microwave and 7.33×10^{-9} to 8.24×10^{-9} m^2/s for infrared drying studies. The activation energies are found to be 9.4654 kW/kg for microwave and 0.3162 kW/kg for infrared drying studies. Energy consumption values were found to be less than 0.1035 and 0.6290 kW h for microwave and infrared drying studies, respectively.

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NAUČNI RAD

KINETIKA I ENERGETSKA POTROŠNJA MIKROTALASNOG I INFRACRVENOG SUŠENJA ČERI PARADAJZA

U ovom radu istraživan je uticaj različitih snaga mikrotalasnog i infracrvenog zračenja na kinetiku sušenja čeri paradajza. Eksperimenti sušenja se izvedeni pri snazi od 90, 180, 270 i 360 W (odnosno gustine snage 5,625, 11,250, 16,875 i 22,500 W/g) pri mikrotalasnom i 74, 83 i 104 V (0,871, 0,976 i 1,224 W/g) pri infracrvenom sušenju. Eksperimentalno određene vrednosti sadržaja vlage korišćeni su za razvoj sedam različitih široko korišćenih modela sušenja u tankom sloju. Rezultati su pokazali da su modeli Veibulla i Aghbashloa i saradnika najbolje fitovali podatke za mikrotalasno i infracrveno sušenje čeri paradajza. Izračunate efektivne difuzivnosti vlage za mikrotalasno i infracrveno sušenje su $5{,}46\times10^{-8}$-$4{,}24\times10^{-7}$ m^2/s i $7{,}33\times10^{-9}$-$8{,}24\times10^{-9}$ m^2/s, redom. Pored toga, energije aktivacije mikrotalasnog i infracrvenog sušenja iznose 9,4654 kW/kg i 0,3162 kW/kg, redom.

Ključne reči: čeri paradajz, kinetika sušenja, infracrveno sušenje, mikrotalasno sušenje, efektivna difuzivnost vlage, energija aktivacije.