Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

Theoretical and experimental analysis of drying kinetics of tomato slices by using infrared dryer

Hany S. EL-Mesery [1, 2], Hanping Mao [1, *]

[1]Key Laboratory of Modern Agriculture Equipment and Technology, School of Chemistry and Chemical Engineering, Jiangsu University, Zhenjiang 212013, PR China
[2]Department of Crop Handling and Processing, Agricultural Engineering Research Institute, Agricultural Research Center, 12311, Giza, Egypt

ARTICLE INFO

Article history:
Received 18 November 2016
Received in revised form
5 January 2017
Accepted 9 January 2017

Keywords:
Infrared
Radiation intensity
Drying kinetics
Theoretical
Tomato slices

ABSTRACT

The infrared radiation drying characteristics of tomato (*Lycopersicon esculentum*) slices have been investigated. The effect of radiation intensity and air velocity on drying kinetics of tomato slices was evaluated. Drying experiments was carried at an infrared radiation intensity of 0.14, 0.20 or 0.35 W/cm^2 and at an air velocity of 0.5, 1.0 or 1.5 m/s with an inlet air temperature of 35±1 °C. During the experiments, tomato slices were dried to final 10 % from 94 % (w.b). The results showed that the drying time decreased with increase in infrared intensity but increased with increase in air velocity. To estimate and select the suitable form of drying curves, eleven different mathematical drying models were applied to experimental data. Among the mathematical models investigated, the Midilli model was found to be the best fit to describe the drying characteristics of tomato slices with highest R^2 and lowest χ^2, RMSE.

1. Introduction

Drying of vegetables and fruits is one of the oldest procedures for food preservation known to man. It is the most important process for preserving food. Because it decreases considerably the water activity of the material, reduces microbiological activity and minimises physical and chemical changes during its storage (Mujumdar and Law, 2010). Drying also brings about substantial reduction in mass and volume, minimising packaging, storage and transportation costs (Sobukola et al., 2007). Natural sun drying is practiced widely in most tropical and subtropical countries and also in Turkey. However, the final product is affected by contamination from insects, dust and spoilage resulting from rain during drying (Lahsasni et al., 2004). Also, traditional sun drying is a slow process compared with other drying methods.

Hot air convection drying is one of the oldest techniques and the most commonly used methods of food drying. Over 85% of industrial dryers use convective hot air systems to drive the evaporation process from the food. Convective drying is accomplished when the heated air is brought into contact with the wet material to be dried to accelerate heat and mass transfer (Zlatanovic et al., 2013). The major disadvantages of hot air drying are low energy efficiency and lengthy drying time during the falling rate period which causes low thermal conductivity. Subsequently, heat transfer in food products during conventional heating is limited (Doymaz, 2011). The problems associated with hot air convective dryers have encouraged researchers to investigate other technologies such as infrared, microwave and vacuum drying of agricultural products.

Infrared radiation heating offers many advantages over conventional hot air drying. When infrared radiation is used to heat or dry moist materials, the radiation impinges the exposed material and penetrates it and then the energy of radiation converts into heat (Xu et al., 2014). Since a material is heated intensely, the temperature gradient is small. Therefore, energy consumption in infrared drying process is relatively low. Introduced energy is transferred from the heating element to the product surface without heating the surrounding air (Hebbar and Rostagi, 2001). The use of infrared radiation technology in dehydrating foods has several advantages. These may include decreased drying time, high energy efficiency, high quality of

---

* Corresponding Author.
Email Address: maohp@ujs.edu.cn (H. Mao)
https://doi.org/10.21833/ijaas.2017.01.020

finished products, uniform temperature in the product while drying, and a reduced necessity for air flow across the product (Zhou et al., 2016; Doymaz et al., 2015; Kocabiyik, 2010).

Mathematical modelling of the drying process and equipment is an important aspect of drying technology in post-harvest processing of agricultural materials. Numerous mathematical equations can be found in literatures that describe drying phenomena of agricultural products. Among them, thin layer drying models have been found wide application due to their ease of use. These models can be categorized as theoretical, semi-theoretical and empirical model (Akpinar, 2006). The theoretical models suggest that the moisture transport is controlled mainly by internal moisture mechanism and needs assumption of geometry of the food material, mass diffusivity and heat conductivity. Semi theoretical models and empirical models consider only the external resistance to the moisture transport and are valid only in the specific range drying conditions. Semi-theoretical models are derived from the general solutions of Fick's second law of diffusion. Empirical models derive a direct relationship between average moisture content and drying time. They neglect fundamentals of the drying process and their parameters have no physical meaning. Therefore, they cannot give clear and accurate view of the important processes occurring during drying although they may describe the drying curve for the conditions of the experiments (Perea-Flores et al., 2012). The objectives of this study were: (i) to study the drying kinetics of tomato slices in infrared radiation dryer as affected by infrared radiation and air velocity and (ii) to evaluate a suitable thin layer drying model among several thin layer drying models to describe the moisture removal behaviour during infrared drying of tomato slices.

2. Theoretical modelling of drying process

For mathematical modelling, the equations in Table 1 were tested to select the best model for describing the drying curve equation of the tomato slices. Those models that were used in this study are presented in Table 1. It also noted that all models are based on the moisture ratio term as Eq. 1.

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where, MR is the moisture ratio, Mt, Mo and Me are moisture content after time t, initial moisture content and equilibrium moisture content, respectively. Moisture ratio (MR) was simplified to Mt/Mi because Me is relatively small compared to Mt or Mi under these drying conditions (Dissa et al., 2011; Perea-Flores et al., 2012).

3. Statistical analysis of models

The drying rate constants and coefficients of the model equations were determined with nonlinear regression of SPSS 16. The goodness of fit of the tested mathematical models to the experimental data was evaluated using eight statistics variables, the correlation coefficient (R^2), the reduced chi-square (χ^2), and the root mean square error (RMSE). The best model describing the drying characteristics of sample was chosen as the one with the highest values of R^2 and the least values of $\chi 2$ and RMSE (Eqs. 2-4) (Kose and Erenturk, 2010).

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp.i} - MR_{Pre.i}\right)^2}{\sqrt{\left[\sum_{i=1}^{N}\left(MR_{exp.i} - MR_{Pre.i}\right)^2\right] * \left[\sum_{i=1}^{N}\left(MR_{exp.i} - MR_{Pre.i}\right)^2\right]}} \tag{2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{exp.i} - MR_{Pre.i}\right)^2}{N}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp.i} - MR_{Pre.i}\right)^2}{N-n} \tag{4}$$

where, $MR_{exp,\,i}$ stands for the experimental moisture ratio as measured, $MR_{pre,\,i}$ is the predicted moisture ratio for the respective measurement, N is the number of observations, n is the number of constants in drying model and MR_{exp} mean is mean value of experimental moisture ratio.

4. Materials and methods

4.1. Experimental material

Fresh tomatoes were purchased from the local market and stored in a refrigerator at 4°C. The tomatoes were removed from the refrigerator and after a stabilization period for 2 hours at the ambient temperature of 25°C the tomatoes were processed. Tomatoes of uniform size were selected, washed and cut into slices of approximately 3 ±0.1 mm thicknesses using a slicing machine. Three measurements were made on each slice for ensuring proper thickness using a calliper and their average values were considered. The initial moisture content of tomato samples was determined using the oven method at 105 °C for 24 h (Horwitz, 2000). Triplicate samples were used for the determination of moisture content, and the average values were reported as 94 % (w.b).

4.2. Experimental apparatus

The infrared dryer comprised of two components i.e. a drying chamber having a tube type infrared heater and a hot air supply unit. The provisions were made in the dryer so that the infrared radiation intensity as well as air temperature could be varied by regulating the voltage through variances. The air velocity was regulated with the help of a damper placed in the air supply line to the drying chamber. The drying chamber of 600×500×500 mm was made from a plywood sheet of 8 mm thickness having a single door opening at the front. The inner sides of the chamber were covered with an aluminium foil. An infrared heater of 1000 W having diameter of 60 mm and length of 300 mm was fitted on the top inside surface of the drying chambers. The output power of the heater could be varied by regulating the voltage through a variance. A sample tray of wire mesh having dimension of 500×400 mm was placed beneath the infrared heater in a way that a distance of 150 mm was maintained between infrared heater and tomato slices in the tray. The hot air supply unit was made of GI sheet having insulation of asbestos from inside. It was fitted with a finned type electrical heater of 1000 W and an axial flow blower forcing the ambient air into dryer through electrical heater. Temperature of the drying air could be regulated through a variance and the air velocity was adjusted through a damper valve in the air supply line. The air temperature was measured using T-type thermocouples (Test 925) connected to a data logger measuring to an accuracy of ±1 °C. The air velocity inside the drying chamber was measured, close to tray, using a hot wire anemometer (Test, 405 V1) which had the working range of 0.1–15 m/s.

Table 1: Mathematical models applied to the drying curves

No.	Name of model	Model equation	References
1	Newton	$MR = \exp(-kt)$	Ayensu (1997)
2	Henderson and Pabis	$MR = a.\exp(-kt)$	Henderson and Pabis (1961)
3	Page	$MR = \exp(-kt^n)$	Page (1949)
4	Modified Page	$MR = \exp[-(kt)^n]$	Ozdemir and Devres (1999)
5	logarithmic model	$MR = a\exp(-kt) + c$	Yagcioglu (1999)
6	Two-term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$	Madamba et al. (1996)
7	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
8	Modified Henderson and pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Karathanos (1999)
9	Midilli et al.	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002)
10	Thomson	$t = a\ln(MR) + b[\ln(MR)]^2$	Thomson et al. (1968)
11	Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	Verma et al. (1985)

4.3. Drying procedure

Experiments to determine the influence of process variables on the drying kinetics of tomato slices was performed. The drying experiments were carried out at inlet air temperature of 35±1 °C, infrared radiation intensity of 0.14, 0.20 or 0.35 W/cm2 and at an air velocity of 0.5, 1.0 or 1.5 m/s, respectively. The dryer was run idle for 30 minute in order to achieve steady state drying conditions before starting each drying experiment. A 400 g mass of tomato slices was uniformly spread as a single layer on a drying container that was then placed on the wire mesh tray. The mass of the tomato was measured using a digital electronic balance every 10 min throughout the drying experiments. In order to measure the mass of the sample during experiments, the sample along with its tray were taken out of the drying chamber and weighed on the digital balance (Mettler PM30, Germany), with the accuracy of ± 0.01 g. The drying process was carried out until the final moisture content of tomato slices was about 10 ± 0.5 % (w.b). All experiments were replicated three times and the average values of the measured data were reported.

5. Results and discussion

5.1. Influence of infrared intensity on drying characteristics

Drying curves at air velocity of 0.5 m/s, air temperature of 35 °C as a function of infrared intensities are shown in Fig. 1. The drying time reduced dramatically with increase in infrared intensity. The drying time to reduce the moisture content of tomato slices to about 10 % (w.b) at infrared intensity of 0.14, 0.20 or 0.35 W/cm^2 was about 360, 315, 225 min, respectively. Motevali et al. (2011) and Ponkham et al. (2011) also observed increased drying rates and decreased drying time of food products with increasing intensity supply to infrared heater. The increase in infrared intensity might have caused a rapid increase in the temperature at surface of product, resulting into an increase in the water vapour pressure inside the product and thus in higher drying rates (EL-Mesery and Mwithiga, 2014).

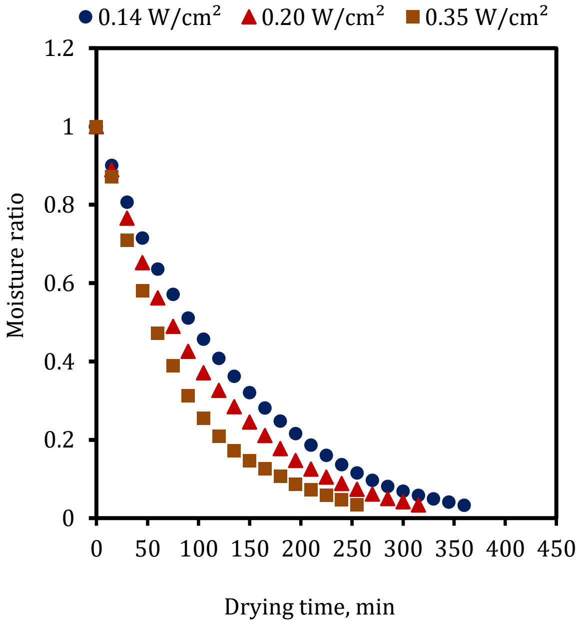

Fig. 1: Drying curves at air velocity of 0.5 m/s, air temperature of 35 °C as a function of infrared intensities

5.2. Influence of air velocity on drying characteristics

The effects of air velocity on moisture ratio of tomato slices during drying at infrared radiation intensity of 0.2 W/cm^2 that corresponds to drying time are shown in Fig. 2. According to the results in Fig. 2, the air velocity level had a significant effect on the moisture ratio of the tomato slices, an increase in air velocity increased the drying time i.e. decreased the moisture removal rate. The moisture ratio at any time was found to be a little higher with higher velocity. The drying time for the tomato slices at air velocity of 0.5 m/s, air temperature of 30 °C and infrared power of 0.2 W/cm^2 was 300 min which increased to 420 min when air velocity was increased to 1.5 m/s. The increase in air velocity accelerated the cooling effect, reducing the temperature at the surface of product thus the water vapour pressure or the moisture driving force. Other researchers who found out that drying time increases with increase in air velocity are Afzal and Abe (2000) while working with barley, Sharma et al. (2005) and while working with onion slices and Nowak and Lewicki (2004) while working with apple slices.

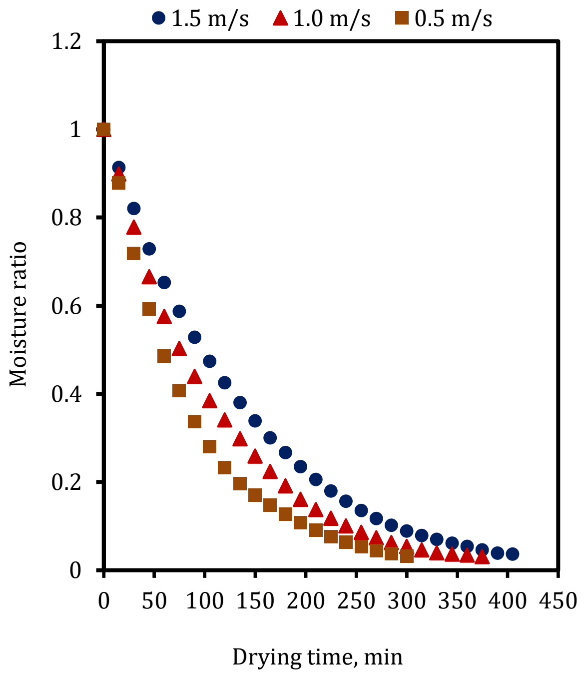

Fig. 2: Infrared radiation drying curves of tomato slices at different air velocities at the infrared radiation intensity of 0.2 W/cm^2

5.3. Evaluation of the models

The average values of the statistical measures (Eqs. 2-4) of the goodness of fit of experimental data to each of the eleven drying models (Table 1) are presented in Table 2. All models could reasonably represent the drying behaviour. This indicates that all the models could satisfactorily describe the infrared drying of tomato. However the Midili model had the highest values of both the R^2 and it also had the lowest values of other statistic parameters χ^2 and RMSE and therefore demonstrated the best fit.

To take into account for the effect of the drying variables on the Midilli et al. (2002) model, the constant of k (min-1) and each of the coefficients of a, n and b were each used in a multiple regression against infrared radiation intensity (IR) in W/cm^2 and drying air velocity (V) in m/s. The coefficient of determination (R^2) ranged between 0.779 and 0.847 while the equations representing these relationships are in form of Eqs. 5-8.

$$k = 0.017 + 0.137\,IR - 0.045\,V - 0.299\,IR^2 + 0.0157\,V^2 + 0.0347\,IR.V \quad R^2 = 0.847 \qquad (5)$$

$$a = 1.11 - 3.23\,IR + 0.381\,V + 6.76\,IR^2 - 0.0158\,V^2 + 0.0258\,IR.V \quad R^2 = 0.798 \qquad (6)$$

$$n = 1.035 - 0.373\,IR + 0.113\,V + 1.02\,IR^2 - 0.0449\,V^2 - 0.159\,IR.V \quad R^2 = 0.819 \qquad (7)$$

$$b = 0.0013 - 0.056\,IR + 0.0073\,V + 0.123\,IR^2 - 0.0028\,V^2 - 0.0023\,IR.V \quad R^2 = 0.779 \qquad (8)$$

The Eqs. 5-8 were further used, together with the Midili model in estimating the moisture ratio and Fig. 3 shows the estimated moisture ratios plotted against experimental values under different drying conditions. As can be seen, the representative symbols in Fig. 3 are closely banding around a 45° straight line and this is a very good agreement between calculated and experimental data. It indicates that, the Midilli et al. (2002) model could adequately describe the drying behaviour of tomato slice over a range of air flow velocities and radiation intensities (Doymaz, 2011).

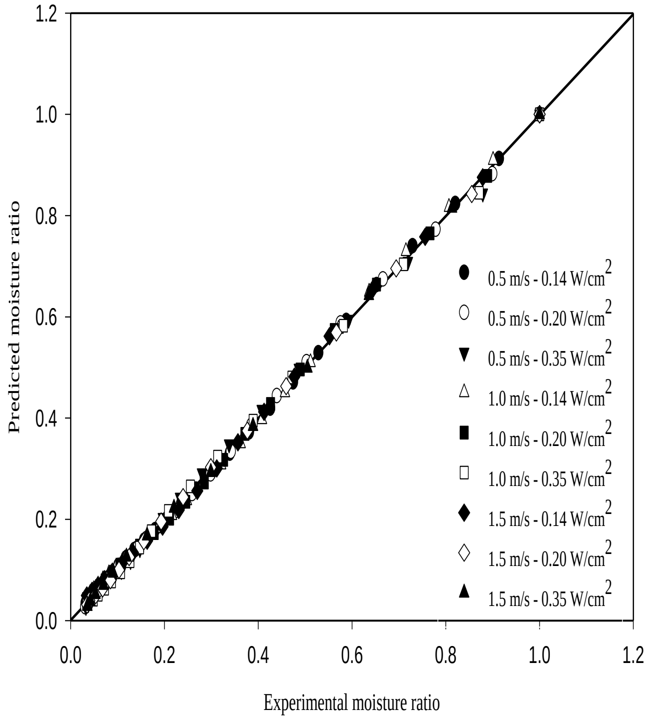

Fig. 3: Experimental and predicted moisture ratio using Midilli et al. model at different drying condition

6. Conclusion

The influence of radiation intensity, drying air velocity on the drying kinetics of tomato slices was investigated in this study. The results showed that the drying time decreased with increase in infrared intensity but increased with increase in air velocity. Based on theoretical analysis, the Midilli et al. (2002) model was the best in describing the infrared drying characteristics of the tomato slices within the rage of experimental conditions.

Table 2: Statistical results of elven models at different drying condition

Name of Model	Infrared intensity, W/cm^2	Drying air velocity								
		0.5 m/s			1.0 m/s			2.0 m/s		
		R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE
Newton	0.14	0.995	0.0023	0.011	0.996	0.0065	0.074	0.998	0.003	0.085
	0.20	0.998	0.0025	0.009	0.997	0.0063	0.055	0.995	0.0051	0.045
	0.35	0.995	0.0096	0.052	0.995	0.0024	0.032	0.991	0.002	0.036
Henderson and Pabis	0.14	0.997	0.0036	0.063	0.988	0.0022	0.065	0.995	0.0096	0.096
	0.20	0.998	0.0009	0.025	0.9914	0.0041	0.054	0.992	0.0025	0.036
	0.35	0.9981	0.0012	0.099	0.992	0.0085	0.099	0.999	0.0036	0.014
Page	0.14	0.9985	0.0009	0.066	0.989	0.00214	0.036	0.997	0.0052	0.025
	0.20	0.9991	0.00251	0.0654	0.988	0.0096	0.024	0.9958	0.0041	0.088
	0.35	0.999	0.0006	0.0663	0.987	0.0052	0.088	0.9965	0.0085	0.088
Modified Page	0.14	0.997	0.0008	0.0087	0.998	0.0039	0.074	0.9958	0.0099	0.044
	0.20	0.996	0.0009	0.0963	0.995	0.00145	0.081	0.9936	0.0047	0.084
	0.35	0.998	0.0007	0.0851	0.9987	0.00256	0.007	0.9991	0.0063	0.095
Logarithmic	0.14	0.998	0.0063	0.0521	0.9871	0.0087	0.0087	0.9978	0.0085	0.065
	0.20	0.997	0.0085	0.0258	0.997	0.00558	0.0097	0.9958	0.0066	0.051
	0.35	0.996	0.0012	0.0962	0.989	0.0012	0.0068	0.9987	0.00885	0.095
Two-term	0.14	0.991	0.0055	0.0078	0.958	0.0008	0.0078	0.993	0.0081	0.008
	0.20	0.995	0.0036	0.009	0.998	0.00095	0.0099	0.9965	0.009	0.008
	0.35	0.997	0.0096	0.088	0.994	0.0007	0.0087	0.9987	0.0078	0.007
Modified Hend. and Pabis	0.14	0.9971	0.0052	0.0551	0.995	0.0025	0.0085	0.996	0.0085	0.0081
	0.20	0.9957	0.0069	0.0526	0.993	0.0014	0.0057	0.999	0.0074	0.0004
	0.35	0.982	0.0009	0.0362	0.998	0.0036	0.0067	0.995	0.008	0.0006
Midilli et al.	0.14	0.9997	0.00051	0.002	0.9998	0.00041	0.0025	0.999	0.0005	0.003
	0.20	0.9998	0.00041	0.003	0.9997	0.00047	0.0045	0.9995	0.00051	0.0024
	0.35	0.9998	0.00031	0.0029	0.9999	0.00039	0.0031	0.9992	0.0004	0.0029
Verma et al	0.14	0.992	0.0025	0.036	0.995	0.0065	0.0089	0.996	0.001	0.012
	0.20	0.998	0.0069	0.074	0.996	0.0039	0.0044	0.996	0.005	0.087
	0.35	0.9984	0.009	0.0145	0.998	0.0085	0.009	0.9987	0.008	0.096
Wang and Sing	0.14	0.998	0.0098	0.0125	0.952	0.0047	0.025	0.9965	0.0041	0.085
	0.20	0.998	0.0088	0.0369	0.966	0.001	0.025	0.998	0.0063	0.0412
	0.35	0.987	0.0063	0.3652	0.991	0.0098	0.036	0.999	0.002	0.0695
Thompson	0.14	0.999	0.00774	0.0078	0.998	0.0005	0.099	0.966	0.0007	0.0055
	0.20	0.997	0.0008	0.0098	0.991	0.0009	0.005	0.987	0.0093	0.008
	0.35	0.994	0.0009	0.0087	0.998	0.0007	0.007	0.998	0.007	0.007

Acknowledgement

We acknowledge that this work was supported by grants from the National Natural Science Foundation of China (No. 51475216), fund name, Damage mechanism in picking up vegetable plug seeding and multi-objective optimization of the seeding pick-up device. The Priority Academic Program Development of Jiangsu Higher Education Institutions (SFE (2014) 37), the Jiangsu Province Synergistic Innovation Center Program of Modern Agricultural Equipment and Technology (No. NZXT02201402), and the Fund for Independent Innovation of the Jiangsu Province Agricultural Science and Technology (No. CX(15)1033-5).

References

Afzal TM and Abe T (2000). Simulation of moisture changes in barley during far infrared radiation drying. Computers and Electronics in Agriculture, 26(2): 137-145.

Akpinar EK (2006). Determination of suitable thin layer drying curve model for some vegetables and fruits. Journal of Food Engineering, 73(1): 75-84.

Ayensu A (1997). Dehydration of food crops using a solar dryer with convective heat flow. Solar energy, 59(4-6): 121-126.

Dissa AO, Bathiebo DJ, Desmorieux H, Coulibaly O, and Koulidiati J (2011). Experimental characterisation and modelling of thin layer direct solar drying of Amelie and Brooks mangoes. Energy, 36(5): 2517-2527.

Doymaz I (2011). Drying of thyme (Thymus Vulgaris L.) and selection of a suitable thin-layer drying model. Journal of Food Processing and Preservation, 35(4): 458-465.

Doymaz I, Kipcak AS, and Piskin S (2015). Characteristics of thin-layer infrared drying of green bean. Czech Journal of Food Sciences, 33(1): 83-90.

EL-Mesery HS and Mwithiga G (2014). Mathematical modelling of thin layer drying kinetics of onion slices hot-air convection, infrared radiation and combined infrared-convection drying. Advances in Environmental Biology, 8(20): 1-19.

Hebbar HU and Rostagi NK (2001). Mass transfer during infrared drying of cashew kernel. Journal of Food Engineering, 47(1): 1–5.

Henderson SM and Pabis S (1961). Grain drying theory I: temperature effect on drying coefficient. Journal of Agricultural Research Engineering, 6(3): 169-174.

Horwitz W (2000). Official methods of analysis of the AOAC International. 17th Edition, Association of Official Analytical Chemists, Gaithersburg, USA.

Karathanos VT (1999). Determination of water content of dried fruits by drying kinetics. Journal of Food Engineering, 39(4): 337–344.

Kocabiyik H (2010). Combined infrared and hot air drying. In: Pan Z and Atungulu GG (Eds.), Infrared heating for food and agricultural processing: 101–116. Taylor and Francis Group, LLC. https://doi.org/10.1201/9781420090994-c6

Kose B and Erenturk S (2010) Drying Characteristics of mistletoe (Viscum album L.) in convective and UV combined convective type dryers. Industrial Crops and Products 32(3): 394-399.

Lahsasni S, Kouhila M, Mahrouz M, Ait Mohamed L, and Agorram B (2004). Characteristic drying curve and mathematical modelling of thin-layer solar drying of prickly pear cladode (Opuntia ficus indica). Journal of Food Process Engineering, 27(2): 103–117.

Madamba PS, Driscoll RH, and Buckle KA (1996). The thin layer drying characteristics of garlic slices. Journal of Food Engineering, 29(1): 75–97.

Midilli A, Kucuk H, and Yapar Z (2002). A new model for single layer drying. Drying Technology, 20(7): 1503–1513.

Motevali A, Minaei S, Khoshtagaza MH, and Amirnejat H (2011). Comparison of energy consumption and specific energy requirements of different methods for drying mushroom slices. Energy, 36(11): 6433-6441.

Mujumdar AS and Law CL (2010). Drying Technology: Trends and Applications in post-harvest processing. Journal of Food Bioprocessing and Technology, 3(6): 843-852.

Nowak D and Lewicki PP (2004). Infrared drying of apple slices. Innovative Food Science and Emerging Technologies, 5(3): 353–360.

Ozdemir M and Devres YO (1999). The thin layer drying characteristics of hazelnuts during roasting. Journal of Food Engineering, 42(4): 225-233.

Page G (1949). Factor influencing the maximum rates of air drying shelled corn in thin layer. M. Sc. Thesis, Purdue University, USA.

Perea-Flores MJ, Garibay-Febles V, Chanona-P_erez JJ Calderon-Dominguez G, Mendez-Mendez JV, Palacios-González E, and Gutierrez-Lopez GF (2012). Mathematical modelling of castor oil seeds (Ricinus communis) drying kinetics in fluidized bed at high temperatures. Industrial Crops Products, 38: 64–71.

Ponkham K and Meeso N, Soponronnarit S, and Siriamornpun S (2011). Modelling of combined far-infrared radiation and air drying of a ring shaped-pineapple with/without shrinkage. Food and Bioproducts Processing, 90(2): 155-164

Sharma GP, Verma RC, and Pathare P (2005). Thin-layer infrared radiation drying of onion slices. Journal of Food Engineering, 67(3): 361–366.

Sobukola OP, Dairo OU, Sanni LO, Odunewu AV, and Fafiolu BO (2007). Thin layer drying process of some leafy vegetables under open sun. Food Science and Technology International, 13(1): 35–40.

Thomson TL, Peart PM, and Foster GH (1968). Mathematical simulation of corn drying: A new model. Transactions of the ASAE; 11(4): 582–586.

Verma LR, Bucklin RA, Endan JB, and Wratten FT (1985). Effects of drying air parameters on rice drying models. Transactions of the ASAE, 28(1): 296–301.

Wang CY and Singh RP (1978). A single layer drying equation for rough rice. ASAE Paper No. 78–3001, ASAE, St Joseph, USA.

Xu C, Li Y, and Yu H (2014). Effect of far-infrared drying on the water state and glass transition temperature in carrots. Journal of Food Engineering, 136: 42–47.

Yagcioglu A (1999). Drying techniques of agricultural products. Ege University, Agricultural Faculty, Publication number: 536, Bornova, Izmir, Turkey.

Zhou L, Xiaoning G, Jinfeng B, Jianyong Y, Qinqin C, Xinye W, and Zhou M (2016). Drying of garlic slices (alliumsativum l.) and its effect on thiosulfinates, total phenolic compounds and antioxidant activity during infrared drying. Journal of Food Processing and Preservation. https://doi.org/10.1111/jfpp.12734

Zlatanovic I, Komatina M, and Antonijevic´ D (2013). Low-temperature convective drying of apple cubes. Applied Thermal Engineering, 53(1): 114–123.