J. Agr. Sci. Tech. (2011) Vol. 13: 155-163

Evaluation of Thin-Layer Drying Models for Simulation of Drying Kinetics of Quercus (*Quercus persica* and *Quercus libani*)

M. Tahmasebi[1], T. Tavakoli Hashjin[1*], M. H. Khoshtaghaza[1], and A. M. Nikbakht[2]

ABSTRACT

Drying characteristics of Quercus were determined experimentally as a function of temperature, air velocity, and variety (*Quercus Persica* and *Quercus Libani*). In order to estimate and select a suitable drying curve, five different thin layer drying models were fitted to the experimental data. Experiments were performed at the air temperatures of 50, 60 and 70°C. At each temperature level, two air velocities were adjusted: 0.5 and 1m/s. The effect of air temperature was found to be significant in comparison to air velocity for drying of fresh Quercus fruits. Increasing air velocity at constant air temperature resulted in the decrease of drying time. Among all the selected drying models, the Page model was found as the best mathematical model for describing the drying kinetics of Quercus fruits. Based on the results, drying temperature of 70 °C and air velocity of 1 m/s are the optimum values for drying Quercus fruit. Drying time and Page model constants were found to be dependent significantly on the variables studied.

Keywords: Drying kinetics, Drying temperature, Page model, Quercus, Thin-Layer drying model.

INTRODUCTION

In the north-west of Iran, approximately 3 million ha of forests are covered by various Oak Quercus species, mainly dominated by *Quercus persica* and *Quercus libani*, (Fatahi, 1995). In this region, Quercus leaves are important sources of forage for goats during periods of the year when quality and quantity of pasture herbages is limited. However, Quercus species have been reported to contain high levels of tannins in both hydrolysable (Makkar, 2003) and condensed (Makkar and Singh, 1991) forms. Drying is the oldest method used for preservation of agricultural products. Early humans found that, after ripening, fruits that were dried naturally on stems were useable. Historically, the sun's rays were used for drying agricultural products but there are many problems in using this method, such as undesirable changes in the quality of food products and a lack of sufficient control during drying, necessitating the use of new technologies in the drying process. Using new technology, the dried Quercus fruit retains its natural color, puffy body and does not undergo any undesirable changes in chemical properties and quality for a relatively long time. Simulation models of the drying process are used for improving existing drying systems predicting the airflow over the product, or even for the control of the process (Xia and Sun, 2002).

Thus, information on the physical and thermal properties of the agricultural products, such as heat and mass transfer, diffusion, thermal conductivity, and specific

[1] Department of Agricultural Machinery Engineering, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.
* Corresponding author, e-mail: ttavakoli@modares.ac.ir
[2] Department of Mechanical Engineering in Agricultural Machinery, Faculty of Agriculture, Urmia University, Urmia, Islamic Republic of Iran.

heat are required for designing an ideal dryer. Thin-layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant drying conditions, i.e., at constant air temperature and humidity. All commercial flow dryers are designed on thin-layer drying principles. Thus, thin-layer drying simulation is the best criterion to model the food drying process (Chakraverty and Singh, 1988). Several researchers have investigated the drying kinetics of various agricultural products in order to determine the best mathematical models for describing thin-layer drying, such as solar drying of prickly pear cladode (Lahsasni *et al.,* 2004), dates (Bakri and Hobani 2000), raw mango slices (Goyal *et al.,* 2006), figs (Babalis *et al.,* 2005), amaranth seeds (Abalone1 *et al.*, 2006), potato slices (Akpinar *et al.,* 2003), sesame hulls (Al-Mahasneh *et al.,* 2007) and Malaysian paddy (Ng *et al.,* 2006).

Although a considerable amount of data has been reported in the literature regarding the thin layer drying modeling of various agricultural products (fruits, crops and vegetables), little information is available on medicinal fruits such as the Quercus fruit. Selection of the best mathematical equation and air condition for thin-layer drying of Quercus fruit was the main objective of this research, in order to apply it for the calculation of drying time and energy consumption for ideal design of a drying system.

MATERIALS AND METHODS

Sample Preparation

Freshly harvested Quercus fruits were purchased from the local farms at Ilam and Urmia cities (Iran) during November 2007 and stored in ventilated plastic bags at a temperature of 2 ºC. Whole fruit samples were used for the experiments as shown in Figure 1. Prior to each drying trial, the Quercuses were poured into a tank of water (flotation grading), in which the floated samples likely to have been rotten, were discarded and only Quercuses which sank in water were used in the experiments (Anila *et al.*, 2008). The initial moisture content of the Quercuses was determined by the oven drying method. About 20 g of sample was dried in an oven at 105ºC for
about 24 h until the mass did not change between two weighing (Koyunco *et al.*, 2004). At least four replicates of experiment were measured. The results showed that the initial moisture content of the fresh *Q. Persica* and *Q. Libani* fruit was about 62% (d.b.).

Drying Condition

A laboratory scale hot-air dryer of the static-tray type developed at the “Agricultural Machinery Laboratory” of Tarbiat Modares University, Tehran, Iran, was used for this study (Figure 2). The main parts of the dryer system consist of an adjustable centrifugal blower, air-heating chamber (2.5 kW), drying chamber, system

(a)

(b)

Figure 1. (a): Defected samples floated in water, (b): fresh samples sank in the vessel.

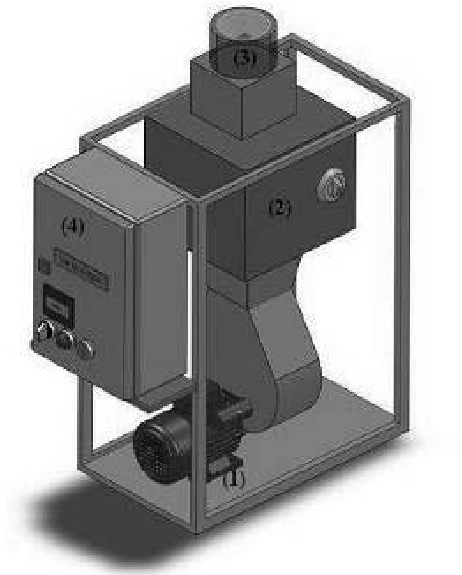

Figure2. Schematic diagram of laboratory scale dryer Electromotor (1), Heater compartment (2), Seed tray (3), Control box (4).

controller, inverter (Lenze 8300, Germany) and tray sample. Experiments were performed at air temperatures of 50, 60 and 70ºC. At each temperature, two velocity values were used: 0.5 and 1 m/s. To decrease the undesirable effects of temperature and humidity of air on the drying experiments, drying chambers and tunnel length were isolated with rock wool. The dryer had an automatic temperature controller with an accuracy of ±0.1ºC. Air velocity was maintained at the mentioned values (0.5 and 1 m/s) with an accuracy of ±0.05 m/s using a PROVA AVM-07 anemometer. The air velocity was fixed using an inverter, which directly acted on the blower motor (1.5 kW). The hot-air orientation on samples was vertical. The first weighing was made at short intervals (approximately every 15 min), gradually increasing to a maximum of every 4 h during experiment. A temperature controller fixed the temperature of the air chamber within ±1ºC. Before the start of any experiment, the dryer system was started in order to achieve steady-state conditions.

Theoretical Considerations

Drying curves were fitted with six different moisture ratio models: the Lewis, the Henderson and Pabis, the Page, the Logarithmic, the Approximation of Diffusion, and the simplified Fick's diffusion models. The moisture ratio of the Quercus fruit during the drying experiments was found using Eq. (1):

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

where MR is the moisture ratio (dimensionless), M_t is the moisture content at any time (kg water/kg dry solid), M_e is the equilibrium moisture content (kg water/kg dry solid) and M_o is the initial moisture content (kg water/kg dry solid). The values of M_e are relatively small compared to those of M_t or M_o, hence the error involved in the simplification is negligible (Diamante and Munro, 1993).

The models implemented in this research are as follows:

The Lewis model (Lewis, 1921):

$$MR = \exp(-kt) \quad (2$$

The Henderson and Pabis model (Henderson and Pabis, 1961):

$$MR = a\exp(-kt) \quad (3$$

Page (1949):

$$MR = \exp(-kt^n) \quad (4$$

The Logarithmic model (Diamante and Munro, 1991) :

$$MR = a\exp(-kt) + c \quad (5$$

The Simplified Fick's diffusion model (Diamante and Munro, 1991):

$$MR = a\exp(-kt\, l^2) \quad (6$$

[DOR: 20.1001.1.16807073.2011.13.2.1.6]

Three criteria were used to determine best fit–coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE). Chi-square and RMSE were calculated using the following equations (Anila *et al.,* 2008):

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp,i} - MR_{pre,i})^2}{N-m} \quad (7$$

$$RMSE = (\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2)^{\frac{1}{2}} \quad (8$$

where $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ is the i_{th} predicted moisture ratio, N is the number of observations and m the number of drying constants. The best fit that could describe the thin-layer drying characteristics of Quercus fruit was selected to yield the highest value of coefficient of determination (R^2), and the lowest value of chi-square (χ^2) and RMSE. To account for the effect of the drying variables on the Page model constants, the constants were regressed against drying air temperature and velocity, using multiple regression analysis. All possible combinations of the different drying variables were tested and included in the regression analysis.

RESULTS AND DISCUSSION

Figures 3 and 4 show the final drying time versus temperature at constant air velocity. It is clear that at high temperature, the difference between total times is negligible whereas at low temperature, the difference between total times is significant. Total time at 0.5 m/s for Liban is about 1.1 times and for *Q. Persica* 1.3 times longer compared with the experiments performed at 1 m/s at constant air temperature. In other words, the effect of air velocity on the total drying time is significant at the varying air temperatures in thin-layer drying of Quercus.

Moisture removal must be continued until free water and some capillarity water exit the Quercus fruit so as to obtain an acceptable dry form of the product. The easiest method to reach this goal is to decrease the vapor pressure around the fruit in the dryer and take the expelled moisture away from the product surface. This is accomplished with proper temperature and hot-air velocity around the fruit surface. Figures 5 and 6 show the drying curves for Quercus fruit at different air temperatures with the constant air velocities. All the curves follow the Page model, as the best chosen model for describing the kinetic drying of Quercus fruit. It is depicted that the drying of Quercus fruit occurs in the falling-rate phase.

Various types of mathematical models have been used to describe drying of food stuffs, ranging from theoretical models based on classical diffusion theory and simplified forms of these to purely empirical models. For the mathematical analysis, It is assumed that the liquid concentration gradient is the main driving force dominating the moisture transfer. The effect of heat transfer is neglected, since the heat transfer proceeds in a rapid manner during drying. Under these conditions, the convective drying of biological materials in

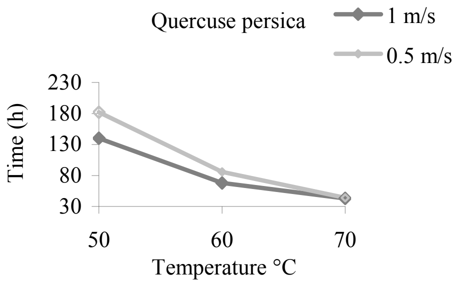

Figure 3. Final time vs drying air temperature at different air velocities for thin-layer drying of *Quercus persica* fruit.

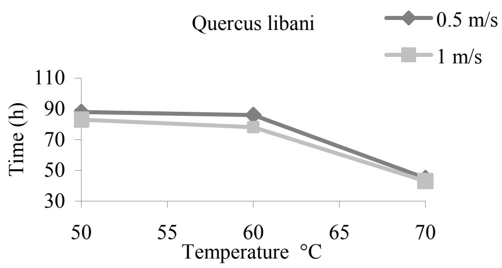

Figure 4. Final time versus drying air temperature at different air velocities for thin-layer drying of *Quercus libani* fruit.

[DOR: 20.1001.1.16807073.2011.13.2.1.6]

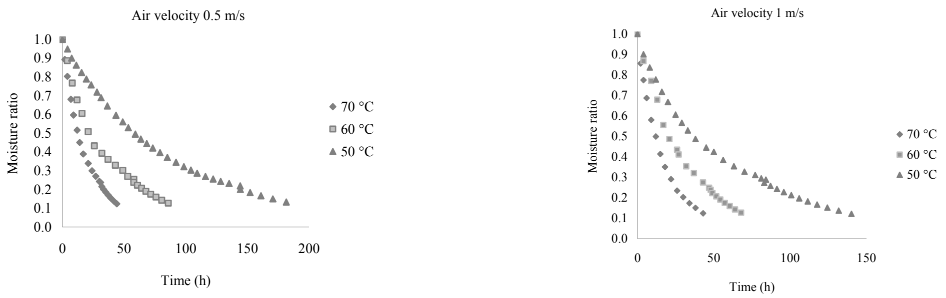

Figure 5. Drying curves for thin-layer drying of *Quercus persica* fruit at different air velocity.

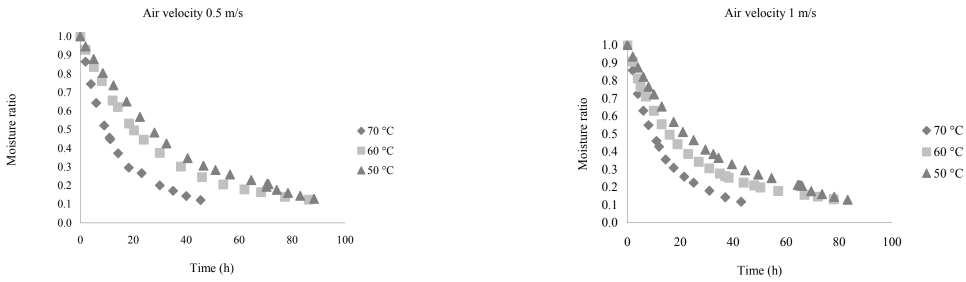

Figure 6. Drying curves for thin-layer drying of *Quercus libani* fruit at different air velocity.

[DOR: 20.1001.1.16807073.2011.13.2.1.6]

the falling rate period is a diffusion-controlled process and may be represented by Fick's second law of diffusion. However, the non-Fickian models have been observed during drying of visco-elastic food materials, where both relaxation and diffusion affect mass transfer (Willis and Okas, 2001). An equation that has been used successfully to describe drying behaviour of a variety of biological material is the Page's model.

In the drying process, internal mass transfer occurs with liquid diffusion, vapor diffusion, and capillary forces in the interior region of the product, and water evaporates as it reaches the surface (Babalis *et al.,* 2005). Moisture removal has capillarity movement when the water content of Quercus fruit is high. Then, water removal occurs through capillary forces to the surface of the fruit with decreasing surface moisture content of the fruit. Pores and free spaces lose water and the ratio of solid material increases in the fruit as the drying process progresses, consequently, the rate of water removal and heat transfer decreases significantly. At the start of the drying process, the moisture of the product is high so the rate of moisture loss is very high; gradually, as time progresses, the product moisture content decreases and so naturally, the rate of moisture loss decreases. It is clear that the product loses most of its moisture in a short time at the beginning of the process, and much time is needed for the remaining moisture to be lost. Multiple regression analysis was performed in MATLAB computer program environment. Tables 1 and 2 show the fitting results (χ^2, R^2 and RMSE) for the models described in equations 2 to 6, using the experimental data, with the best-fitting model in bold type. Acceptable R^2 values i.e. greater than 0.97, were obtained for all fitted models in all drying experiments. The best model describing the thin-layer drying kinetics was selected with the highest R^2 average values, and the lowest χ^2 and RMSE average values. By comparing the R^2, χ^2 and RMSE average values, it is clear that the Page model has the best fits to the experimental data. The Page model constants are reported in Table 3. In all of the experiments, the Page model showed the best agreement for thin-layer drying curves of Quercus fruit.

Table 1. Coefficient of determination (R^2), Chi-Square (χ^2) and root mean square error (RMSE) for 0.5 m/s air velocity.

Variety	Model	50°C			60°C			70°C		
		R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Q. Persica	Lewis	0.9981	0.0112	0.00466	0.9807	0.0355	0.02521	0.9930	0.0223	0.00946
	Henderson and Pabis	0.9988	0.0089	0.00249	0.9868	0.0300	0.01716	0.9947	0.0199	0.00718
	Page	0.9995	0.0059	0.00110	0.9961	0.0163	0.00504	0.9981	0.0120	0.00261
	The Logarithmic model	0.9988	0.0086	0.00235	0.9957	0.0166	0.00555	0.9957	0.0181	0.00621
	The Approximation of Diffusion model	0.9988	0.0091	0.00249	0.9968	0.0308	0.01716	0.9947	0.0205	0.00718
Q. Libani	Lewis	0.9967	0.0166	0.00555	0.9893	0.0298	0.01424	0.9745	0.0444	0.02565
	Henderson and Pabis	0.9970	0.0161	0.00495	0.9915	0.0275	0.01137	0.9794	0.0416	0.02080
	Page	0.9980	0.0131	0.00330	0.9971	0.0161	0.00390	0.9939	0.0226	0.00617
	The Logarithmic model	0.9848	0.0347	0.02539	0.9968	0.0176	0.00499	0.9895	0.0324	0.01367
	The Approximation of Diffusion model	0.9970	0.0165	0.00495	0.9915	0.0284	0.01137	0.9794	0.0434	0.02080

Table 2. Coefficient of determination (R^2), Chi-Square (χ^2) and root mean square error (RMSE) for 1 m/s air velocity.

Variety	Model	50°C			60°C			70°C		
		R^2	RMSE	χ^2	R^2	RMSE	χ^2	R^2	RMSE	χ^2
Q. Persica	Lewis	0.9821	0.03321	0.03088	0.9964	0.01553	0.00458	0.9838	0.03991	0.0207
	Henderson and Pabis	0.9916	0.02318	0.01451	0.9966	0.01539	0.00426	0.9922	0.02885	0.0099
	Page	0.9985	0.00984	0.00261	0.9973	0.01378	0.00341	0.9968	0.02171	0.0056
	The Logarithmic model	0.9964	0.01554	0.00676	0.9932	0.02117	0.00852	0.9838	0.04338	0.0207
	The Approximation of Diffusion model	0.9916	0.02362	0.01451	0.9966	0.01583	0.00426	0.9922	0.30140	0.0099
Q. Libani	Lewis	0.9850	0.03348	0.02691	0.9655	0.04977	0.05201	0.9815	0.03734	0.01813
	Henderson and Pabis	0.9901	0.02782	0.01780	0.9778	0.04085	0.03337	0.9860	0.03387	0.01376
	Page	0.9976	0.01374	0.00434	0.9955	0.01846	0.00681	0.9968	0.01614	0.00312
	The Logarithmic model	0.9878	0.03142	0.02992	0.9197	0.07411	0.12081	0.9893	0.03190	0.01331
	The Approximation of Diffusion model	0.9901	0.02844	0.01780	0.9778	0.04191	0.03337	0.9860	0.03537	0.01376

Table 3: Constants related to the Page model for each experiment.

Variety	Air velocity	0.5 m/s		1 m/s	
	Temperature °C	k	n	k	n
Q. Persica	50	0.03	0.79	0.03	0.88
	60	0.07	0.76	0.05	0.86
	70	0.06	0.91	0.06	0.91
Q. Libani	50	0.04	0.90	0.05	0.82
	60	0.05	0.85	0.09	0.73
	70	0.12	0.77	0.11	0.80

Generally, R^2, χ^2 and RMSE values for the Page model were 0.9807–0.9995, 0.0011 to 0.3014 and 0.0059–0.0355 for *Q. Persica* and 0.9197-0.998, 0.00312 to 0.12081 and 0.0131-0.07411 for *Q. Libani*, respectively. The Page model constants were regressed against air condition using multiple regression, and the equation and the corresponding R^2 values are reported. Regression analysis for these parameters yielded the following relationships at the statistically significant level of 1% for *Q. Libani*:

$$k = -0.7V^{0.64}\exp(\frac{1}{T_{abs}}) \qquad 0.9774= R^2 \qquad (9$$

$$n = 0.067V^{0.051}\exp(\frac{1}{T_{abs}}) \qquad 0.9097= R^2 \qquad (10$$

Consequently, the following equation was obtained for thin-layer drying of Quercus fruit:

$$MR = f(t,T,V) =$$

$$\exp(-0.7V^{0.64}\exp(\frac{1}{T_{abs}})t^{0.07V^{0.05}\exp(\frac{1}{T_{abs}})}) \qquad (11$$

Figure 7 shows the experimental data versus the predicted values using the Page model. Data points are banded around a 45° straight line:

$$MR_{pre} = 0.995MR_{\exp} + 0.0021$$
$$R^2 = 0.9958 \qquad (12$$

It is clear that the selected model shows a good agreement between the predicted data and the experimental moisture ratio values for drying fresh Quercus fruit.

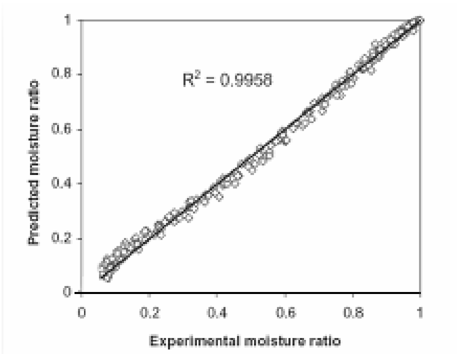

Figure 7. Predicted vs. experimental moisture ratio values using the Page model for different air temperature and velocity values for thin-layer drying of Quercus fruit.

An analysis of variance (ANOVA) was conducted to assess the significant effects of the independent variables on the responses and to determine which of the responses were significantly affected by the varying treatment combinations (Table 4). As depicted in Table 4, the effect of all factors (variety, temperature and air velocity) on the time of drying is significant (P>0.01).

CONCLUSION

The drying curves of fresh Quercus fruit occurred in the falling rate period. Compared with the effect of air velocity, the effect of temperature was significant on the drying time for fresh Quercus fruit; on the other hand, by increasing air velocity at constant air temperature, the drying time decreased. The Page model had the best fit to the experimental data with the highest average values of R^2, and

[DOR: 20.1001.1.16807073.2011.13.2.1.6]

Table 4: Analysis of variance for the investigation of the effect of factors on time.

Dependent Variable: Time		
Source of variation	df	Mean Square
Variety(R)	1	30523.796**
Air Temperatures (T)	2	111755.382**
Velocity(V)	1	10376.489**
R * T	2	29181.689**
T * V	2	825.974 n.s.
R * V	1	1472.549 n.s.
R * T * V	2	598.702 n.s.
Error	735	1240.760
Total	747	
Corrected Total	746	

ns: Non-significant. * Significant at 0.05 level. ** Significant at 0.01 level.

the lowest average values of $\chi^2$and RMSE. Case hardening may occur if air orientation is concurrent with fresh Quercus fruit at the start of the drying process because of high initial moisture content (62% d.b). Moreover, the required time for Quercus fruit drying increases dramatically, specifically at high levels of air velocity. Moisture removal must be continued until free water and some capillarity water exit the Quercus fruit so as to obtain an acceptable dry form of the product. It would be possible to attain faster drying with increased drying temperature up to 70 ºC. From the results obtained in this work, it is possible to infer that the choice of higher temperatures allows faster drying rates, resulting in faster dehydration processes, with important economical benefits. Drying temperature of 70 ^{o}C and air velocity of 1 m/s were the optimum values for drying Quercus fruit. The Page model was found to be quite good to describe the drying behavior of these varieties of Quercus in the range of the temperatures studied.

Nomenclature

a, *b*, *c*, *n*, *k*, *l*:	Constants
Me:	Equilibrium moisture content (kg water/kg dry solid)
M_t:	moisture content at any time (kg water/kg dry solid)
V:	air velocity (m/s)
MR:	moisture ratio (-)
R^2:	coefficient of determination
T:	time (h)
M:	bulk moisture content (kg water/kg dry)
M_0:	initial moisture content (kg water/kg dry solid)
N:	number of observation
m:	number of drying constants
RMSE:	root mean square error
χ^2:	chi-square
K:	absolute air temperature

REFERENCES

1. Abalone, R. Gasto, A. Cassinera, A. Lara, M.A. 2006. Thin-layer Drying of Amaranth Seeds. *Bios. Engin*. **93(2)**: 179–188
2. Akpinar, E., Midilli, A. and Bicer, Y. 2003. Single Layer Drying Behavior of Potato Slices in a Convective Cyclone and Mathematical Modeling. *Energy Convers. Manage*. **44**: 1689–1705.
3. Al-Mahasneh, M. A., Rababah, T. M., Al-Shbool, M. A. and Yang, W. 2007. Thin-Layer Drying Kinetics of Sesame Hulls under Forced Convection Open Sun Drying. *J. Food Process Eng*. **30(3)**: 324–337.
4. Anila, B. C., James, K, C. 2008. Drying Curves and Apparent Diffusivity of New Zealand Chestnut Variety ‘1015’. *J. Food Engin*. **85**: 381–386.
5. Babalis, S. J., Papanicolaou, E., Kyriakis, N. and Belessiotis, V. G. 2005. Evaluation of Thin-layer Drying Models for Describing Drying Kinetics of Figs (*Ficus carica*). *J. Food. Eng*. **75**: 205–214.
6. Bakri, H. H. and Hobani, A. I. 2000. Thin-Layer Drying of Dates. *J. Food Process Eng*. **23(3)**: 177–189.
7. Chakraverty, A. and Singh, R. P. 1988. Post-harvest Technology of Cereals, Pulses and Oilseeds, Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, India.
8. Diamante, L. M. and Munro, P. A. 1991. Mathematical Modeling of Hot Air Drying of Sweet Potato Slices. Znt. *J. Food Sci. Technol.*, **26**: 99-109.
9. Diamante, L. M. and Munro, P. A. 1993. Mathematical Modeling of the Thin-layer

Solar Drying of Sweet Potato Slices. *Solar Energy*, **51**: 271–276.

10. Fatahi, M. 1995. Investigation of Zagros Oak Forests and the Major Destruction Reasons. Forests and Prairie Research Institute, 101, pp: 61.
11. Goyal, R. K., Kingsly, A. R. P., Manikantanl, M. R. and Ilyas, S. M. 2006. Thin-layer Drying Kinetics of Raw Mango Slices. *Biosyst. Eng.* **95(1)**: 43–49.
12. Henderson, S. M. and Pabis, S. 1961. Grain Drying Theory: 1. Temperature Affection Drying Coefficient. *J. Agric. Eng. Res.* **6**: 169–170.
13. Koyunco, M. A., Ekinci, K. and Savran, E. 2004. Cracking Characteristics of Walnut. *Bios. Engin.* **87(3)**: 305-311
14. Lahsasni, S., Kouhila, M., Mahrouz, M., AIT Mohamed, L. and Agorram, B. 2004. Characteristic Drying Curve and Mathematical Modeling of Thin-layer Solar Drying of Prickly Pear Cladode (*Opuntia ficus* indica). *J. Food Process Eng.* **27(2)**: 103–117.
15. Lewis,W. K. 1921. The Rate of Drying of Solid Materials. *Ind. Eng. Chem.* **13**: 427–432.
16. Makkar, H. P. S., 2003. Effects and Fate of Tannins in Ruminant Animals, Adaptation to Tannins, and Strategies to Overcome Detrimental Effects of Feeding Tannin-rich Feeds. *Small Ruminant Res.* **49**: 241–256.
17. Makkar, H. P. S., and Singh, B., 1991. Composition, Tannin Levels and in-sacco Dry Matter Digestibility of Fresh and Fallen Oak (*Quercus incana*) Leaves. *Bioresour. Technol.*, **37**: 185-187.
18. Ng, P. P., Tasrian, S. M. and LAW, C. L. 2006. Thin Layer Method Analysis of Spouted Bed Dried Malaysian Paddy Characteristic Drying Curves. *J. Food Process Eng.* **29(4)**: 414–428.
19. Page, G. E. 1949. Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin Layers. MSc Thesis, Purdue University, West Lafayette, IN.
20. Willis, B., Okas, M. R., 2001. Mass Transfer Model for Amorphous Shrinking Food Materials. In: IFT Annual Meeting, New Orleans, LA.
21. Xia, B. and Sun, D. W. 2002. Application of Computational Fluid Dynamics (CFD) in the Food Industry: A Review. Comput. Electron. Agric. **34**: 5–24.

ارزیابی مدلهای خشک شدن لایه نازک برای توصیف سینتیک خشک کردن بلوط (*Quercus persica* and *Quercus libani*)

م. طهماسبی، ت. توکلی هشجین، م. ه. خوش‌تقاضا و ع. م. نیک‌بخت

چکیده

ویژگی‌های خشک شدن بلوط بر حسب تابعی از دما، سرعت هوا و رقم (*Q. Persica , Q. Libani*) تعیین شد. به منظور تخمین و انتخاب یک مدل مناسب، منحنی خشک شدن، پنج مدل نیمه تئوری و یا تجربی به داده‌های آزمایشگاهی برازش شده‌اند. آزمایشات در سه دمای ۵۰، ۶۰ و ۷۰ درجه سانتیگراد انجام گرفت. در هر دما دو جریان هوای ۰/۵ و ۱ متر بر ثانیه نیز تنظیم شد. تاثیر دمای هوا در مقایسه با جریان هوای خشک‌کن در فرآیند خشک کردن میوه بلوط از اهمیت بیشتری برخوردار بود. افزایش جریان هوای خشک‌کن در دمای هوای ثابت زمان خشک شدن را کاهش داد. از میان تمام مدلهای انتخاب شده، مدل پیج به عنوان بهترین مدل ریاضی به منظور بیان سینتیک خشک شدن بلوط انتخاب شد. بر اساس نتایج بدست آمده، دمای ۷۰ درجه سانتیگراد و سرعت جریان هوای ۱ متر بر ثانیه بهترین نتایج را برای خشک کردن میوه بلوط در بر داشت. زمان خشک‌شدن و ثابت‌های مدل پیج با متغیرهای مطالعه شده وابستگی معنی داری داشتند.

[DOR: 20.1001.1.16807073.2011.13.2.1.6]