Cercetări Agronomice în Moldova
Vol. XLV , No. 2 (150) / 2012

MODELING SOME DRYING CHARACTERISTICS OF CANTALOUPE SLICES

R.A. CHAYJAN[1]*, H.H. AGHA-ALIZADE[1], H. BARIKLOO[1], B. SOLEYMANI[1]

*E-mail: amirireza@basu.ac.ir

Received January 3, 2012

ABSTRACT. This study investigated thin layer drying of cantaloupe slices under different drying conditions with initial moisture content about 18.53 (d.b.). Air temperature levels of 40, 50, 60 and 70°C were applied in drying of samples. Fick´s second law in diffusion was applied to compute the effective moisture diffusivity (D_{eff}) of cantaloupe slices. Minimum and maximum values of D_{eff} were 4.05×10^{-10} and 1.61×10^{-9} m^2/s, respectively. D_{eff} values increased as the input air temperature was increased. Activation energy values of cantaloupe slices were found between 30.43 and 36.23 kJ/mol for 40°C to 70°C, respectively. The specific energy consumption for drying cantaloupe slices was calculated at the boundary of 1.01×10^5 and 9.55×10^5 kJ/kg. Increasing in drying air temperature in different air velocities led to increase in specific energy value. Results showed that applying the temperature of 70°C is more effective for convective drying of cantaloupe slices. The aforesaid drying parameters are important to select the best operational point of a dryer and to precise design of the system.

Key words: Drying; Moisture diffusivity; Cantaloupe; Kinetic; Activation energy.

INTRODUCTION

Cantaloupe (*Cucumis melo* L.) is an important source of vitamins A, B and C as well as sugars. It can be utilized as fresh, dried and fruit juice. Total production of cantaloupe fruit in the world is 27×10^6 t per year. Soil and climatic condition in Iran, are suitable to cantaloupe cultivation. The cultivated area of cantaloupe in Iran is about 8×10^4 ha with an annual production of 127×10^4 t (FAOSTAT, 2009). A small amount of this production is exported and the major part is consumed domestically (Behbahani, 2005).

Cantaloupe is a seasonal crop and due to high initial moisture content is very sensitive to microbial spoilage. So drying the fruit after harvesting is necessary in order to consume in a long period (Doymaz, 2007). The main goal in cantaloupe slice drying is reducing moisture

---

[1] Bu-Ali Sina University, Faculty of Agriculture, Department of Mechanics of Agricultural Machinery, Hamadan, Iran

content to a specific level, for safe storage in a long period of time (Erenturk and Erenturk, 2007). Thus, drying of cantaloupe slice by elimination of the water from the slices reduces the deterioration phenomena due to the presence enzymes or micro-organisms (Sacilik, 2007). Other benefits of cantaloupe slice drying are longer shelf-life, lighter weight, storability under ambient temperatures and smaller space for storage (Hashemi *et al.,* 2009).

Effective moisture diffusivity, activation energy and specific energy consumption are three important factors in modeling, designing and optimizing of a drying process. Moisture migration during drying process is controlled by diffusion phenomenon. Moisture movement rate is explained by effective moisture diffusivity (Bakal *et al.,* 2010). Activation energy is minimum required energy to start the drying process (Aghbashlo *et al.,* 2008). Specific energy consumption is required energy to evaporate 1 kg water from cantaloupe slices. Accordingly, applying suit level of temperature and air velocity is important (Chayjan *et al.,* 2011a).

Although many studies have been performed about drying of different food and agricultural products, nevertheless no study has been conducted about drying of cantaloupe slices. Additionally, drying indices of cantaloupe slices is not available.

The main objectives of this study were: 1) to compute the drying indices (effective moisture diffusivity, activation energy and specific energy consumption) for cantaloupe slices and 2) to establish relationships between input parameters (air temperature and velocity) and drying indices.

MATERIALS AND METHODS

Sample preparation. Freshly harvested cantaloupe fruit were purchased from a local market. The samples were stored in a refrigerator at about +5°C. Initial moisture content of fresh cantaloupe fruit was determined using oven method. About 20 g of cantaloupe slices (3 mm thickness) with five replicates was dried at 70±1°C for 24 hours. Initial moisture content of the slices was about 18.53 (w.b.). Experiments were conducted at input air temperatures of 40, 50, 60 and 70°C. Three air velocity values were adjusted at each temperature: 0.6, 1.8 and 3 m/s.

Drying condition. A laboratory scale thin layer dryer was implemented in this study. Air relative humidity of the laboratory was about 28-33% and the ambient air temperature was about 24–26°C. A digital thermostat with ±0.1ºC accuracy was used to control the inlet air temperature (Atbin mega, made in Iran). An inverter was applied to control the air velocity through controlling the blower speed with ±0.1 Hz accuracy (Vincker VSD2, made in Taiwan). An anemometer Standard ST-8897 model was used to adjust the input air velocity. A precision balance with accuracy of 0.01 g was implemented for sample weighing. Firstly weighing was carried out at periods of 3 minutes, gradually weighing periods increased to the maximum of 10 minutes during the experiment. Before starting the experiments, the dryer was turn on to achieve a steady state condition. Ambient air temperature, air relative humidity, inlet and outlet drying air temperatures were recorded during the experiments.

Theoretical principle. Fick's second law of unsteady state diffusion for infinite slab body was applied to describe the transport of moisture during the falling rate process that occurred in the cantaloupe slices:

$$\mathrm{MR} = \frac{\mathrm{M}-\mathrm{M_e}}{\mathrm{M_0}-\mathrm{M_e}} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\exp\left(\frac{-\mathrm{D_{eff}}(2n-1)^2\pi^2 t}{4L^2}\right) \tag{1}$$

where $n = 1, 2, 3, \ldots$ is the number of terms; t is drying time (s); D_{eff} is effective moisture diffusivity (m^2/s) and L is half thickness of cantaloupe slices (m).

Only first term of Eq. (1) is considered for a long drying period (Kingsly *et al.*, 2007). The relationship obtained as follow:

$$\mathrm{MR} = \left(\frac{8}{\pi^2}\right)\exp\left(\frac{\pi^2 \mathrm{D_{eff}} t}{4L^2}\right) \tag{2}$$

The linear form of Eq. (2) is as follow:

$$\ln(\mathrm{MR}) = \ln\left(\frac{\mathrm{M}-\mathrm{M_e}}{\mathrm{M_0}-\mathrm{M_e}}\right) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\mathrm{D_{eff}}\pi^2 t}{4L^2}\right) \tag{3}$$

Activation energy (E_a) was calculated using the Arrhenius equation (Babalis and Belessiotis, 2004):

$$\mathrm{D_{eff}} = \mathrm{D_0}\exp\left(-\frac{\mathrm{E_a}}{\mathrm{RT}}\right) \tag{4}$$

E_a can be obtained by changing the Eq. (4) as follows:

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

where E_a is activation energy (kJ/mol); D_0 is pre-exponential factor of the equation (m^2/s); R is universal gas constant (8.3143 kJ/mol.K); T is absolute air temperature (K). After drawing *1/T* against *ln(D_{eff})* according to Eq. (5), three linear models were plotted. Specific energy consumption (*SEC*) of cantaloupe slices drying was computed using the following equation (Zhang *et al.*, 2002):

$$\mathrm{SEC} = \frac{(\mathrm{C_{Pa}} + \mathrm{C_{Pv}}\mathrm{h_a})\mathrm{Qt}(\mathrm{T_{in}} - \mathrm{T_{am}})}{\mathrm{m_v}\mathrm{V_h}} \tag{6}$$

where *SEC* is specific energy consumption (kJ/kg); C_{Pv} and C_{Pa} are specific heat capacity of vapor and air, respectively (1004.16 and 1828.8 J/kg °C); Q is the inlet air to drying chamber (m^3/s); t is the total drying time (min); h_a is absolute air humidity ($kg_{vapor}/kg_{dry\ air}$); T_m and T_{am} are inlet air to drying chamber and ambient air temperatures, respectively (°C); m_v is mass of removal water (kg) and V_h is specific air volume (m^3/kg).

RESULTS AND DISCUSSION

Drying kinetic. Drying time against moisture ratio (MR) of cantaloupe slices at different temperature levels (40, 50, 60 and 70 °C) and air velocities (0.6, 1.8 and 3 m/s) was plotted (*Fig. 1*). As can be seen, input air temperature has an important effect in drying time of cantaloupe slices. An increase in input air temperature caused a notable decrease in drying time. With increasing the input air temperature, more energy rate applied to the cantaloupe slices and cause increase in drying rate. These results are similar to the previous studies, such as: tarragon (Arabhosseini *et al.* 2009), mushroom (Arumuganathan *et al.*, 2009) and red beet (Kaleta and Górnicki, 2010).

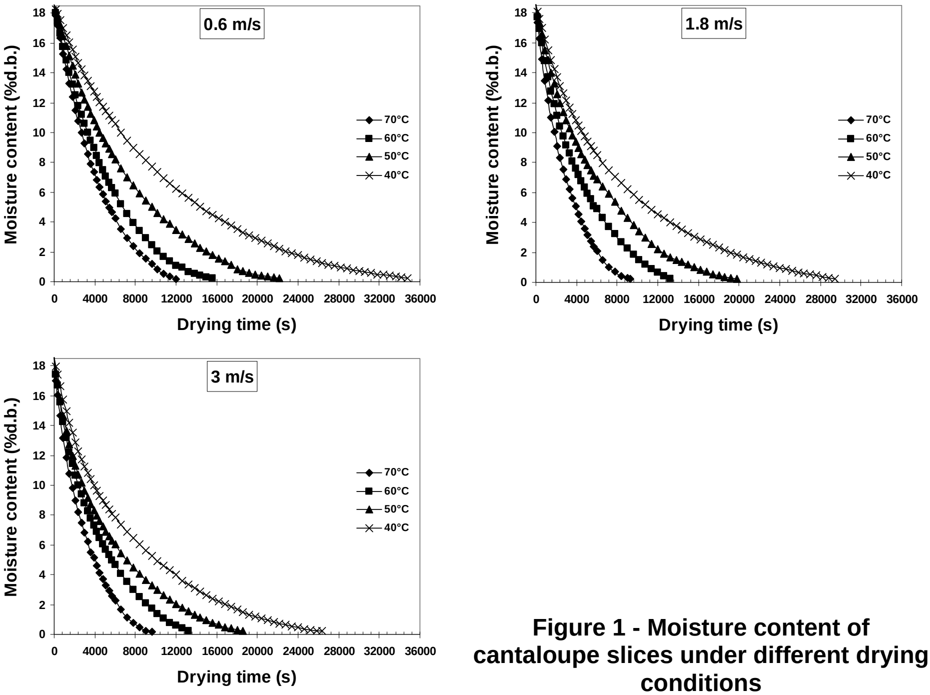

Figure 1 - Moisture content of cantaloupe slices under different drying conditions

Effective moisture diffusivity. Firstly, *ln(MR)* values were plotted against drying time of all drying conditions (*Fig. 2*). Results showed that the drying process of cantaloupe slices was performed as liquid diffusion. With regard to small thickness of cantaloupe slices (about 3 mm), drying process was occurred in falling rate period. Increase in input temperature cause increase in curve slope. Air velocity has little effect on slope of D_{eff}; so that the increase in air velocity has not significant effect on D_{eff}, especially at low temperature levels. D_{eff} values (*Table 1*) were computed by Eq. (3). Minimum and maximum values of D_{eff} were 4.05×10^{-10} m^2/s and 1.61×10^{-9} m^2/s, respectively. Maximum value calculated at air temperature of 70°C and air velocity of 1.8 m/s. But any significant effect did not observed between air velocity of 1.8 and 3 m/s in this temperature level. Minimum value of D_{eff} belonged to air velocity of 0.6 m/s with air temperature of 40°C. These results showed that the air velocity of 1.8 m/s is the best selected point for drying of cantaloupe slices in the experimental domain, because D_{eff} value for this air velocity level was relatively higher. This condition concluded lower energy consumption by electrical heater and motor and less mechanical damage of product.

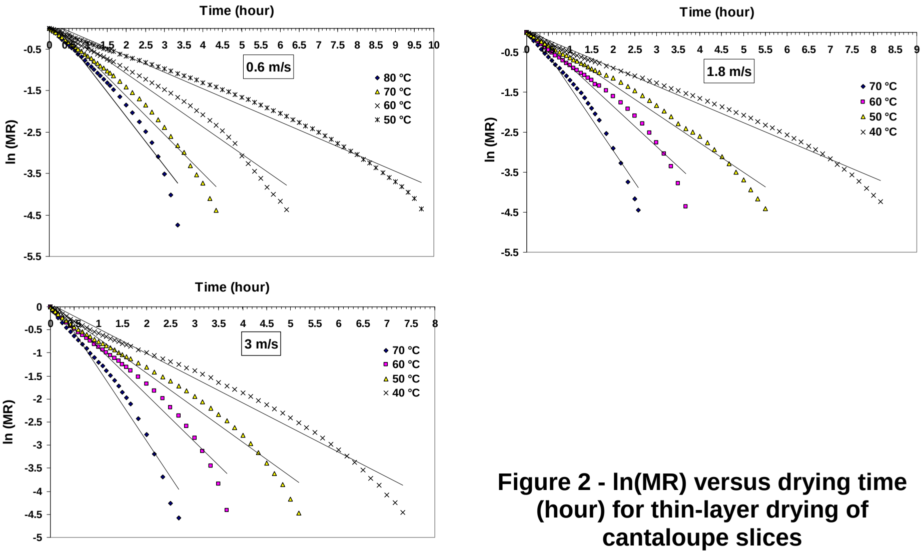

Figure 2 - ln(MR) versus drying time (hour) for thin-layer drying of cantaloupe slices

Table 1 - Effective moisture diffusivity of cantaloupe slices for different drying conditions

T (°C)	Air velocity (m/s)					
	0.6		1.8		3	
	D_{eff} (m^2/s)	R^2	D_{eff} (m^2/s)	R^2	D_{eff} (m^2/s)	R^2
40	4.05×10^{-10}	0.9808	4.64×10^{-10}	0.9847	5.42×10^{-10}	0.9793
50	6.57×10^{-10}	0.9690	7.39×10^{-10}	0.9807	7.59×10^{-10}	0.9752
60	9.49×10^{-09}	0.9747	1.02×10^{-09}	0.9617	1.03×10^{-09}	0.9647
70	1.34×10^{-09}	0.9499	1.61×10^{-09}	0.9687	1.59×10^{-09}	0.9603

Input air temperature has greater effect on D_{eff} values of cantaloupe slices. This affect is more sensible in higher temperature levels. Similar results have been reported by many researchers, such as: canola (Gazor, 2009) and corn (Chayjan *et al.*, 2011a).

D_{eff} values for all input air temperatures and air velocities have been shown in *Fig. 3*. Three exponential models were fitted on D_{eff} values for three air velocities (*Table 2*). The R^2 values indicated that the applied models are suitable to predict D_{eff} based on input air temperature. Also three models of two order polynomial type were fitted to predict the D_{eff} in different air velocities (*Table 3*). Increasing of D_{eff} in each air velocity was based on exponential pattern. Also due to no significant effect of input air velocity on mass transfer of cantaloupe slices, so very little changes was observed in D_{eff} values of each air velocity.

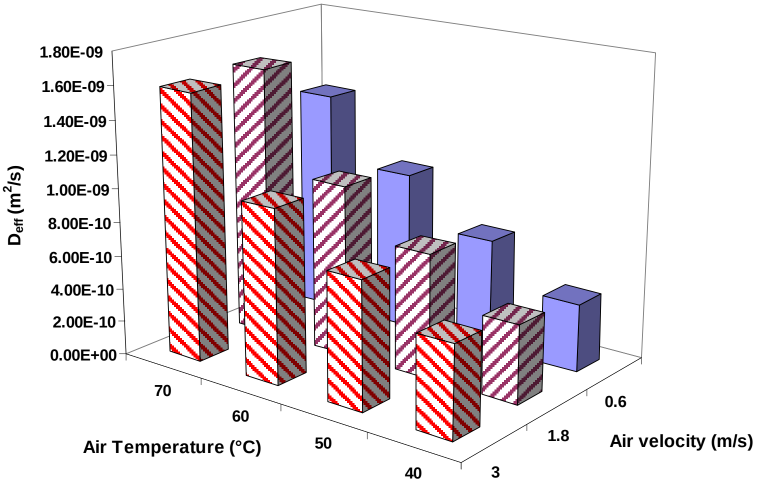

Figure 3 - D_{eff} of cantaloupe slices under different drying conditions

Table 2 - D_{eff} modeling by three exponential equations at different air velocities

Air velocity (m/s)	Fitted model	R^2
0.6	$D_{eff} = 9\times10^{-11}\times\exp(0.039T)$	0.9930
1.8	$D_{eff} = 9\times10^{-11}\times\exp(0.040T)$	0.9950
3	$D_{eff} = 1\times10^{-10}\times\exp(0.035T)$	0.9950

Table 3 - D_{eff} modeling of cantaloupe slices using four polynomial models at different air temperatures

Air temperature (°C)	Model	R^2
40	D_{eff} = 7×10-12×v2 -3×10-11×v + 4×10^{-10}	1
50	D_{eff} = -2×10-11×v2 - 10-10×v + 6×10^{-10}	1
60	D_{eff} = -2×10-11×v2 - 10-10×v + 9×10^{-10}	1
70	D_{eff} = -10-10×v2 + 5×10-10× v + 10^{-9}	1

Activation energy. ln(D_{eff}) against 1/T was plotted for cantaloupe slices (*Fig. 4*). Three graphs were obtained. Slope of the curves considered to compute the activation energy (E_a). E_a of cantaloupe slices for all drying conditions and related R^2 values are reported in *Table 4*. E_a domain for agricultural and food products is reported 12 to 110 kJ/mol (Babalis and Belessiotis, 2004).

E_a values for cantaloupe slices varied between 30.43 and 36.23 kJ/mol for air velocities of 0.6 and 1.8 m/s, respectively. Two form of water in agricultural and food products are free and bounded moisture. Most of the water in cantaloupe slices is in the form of bounded moisture. As a result, drying the samples was performed in falling rate. This phenomenon causes an increase in activation energy of cantaloupe slices. In the falling period, temperature and air velocity have not significant effect on moisture transfer. As a result, increase in input air velocity leads to increase in energy consumption and increase in input air temperature causes injuries in physical and chemical properties.

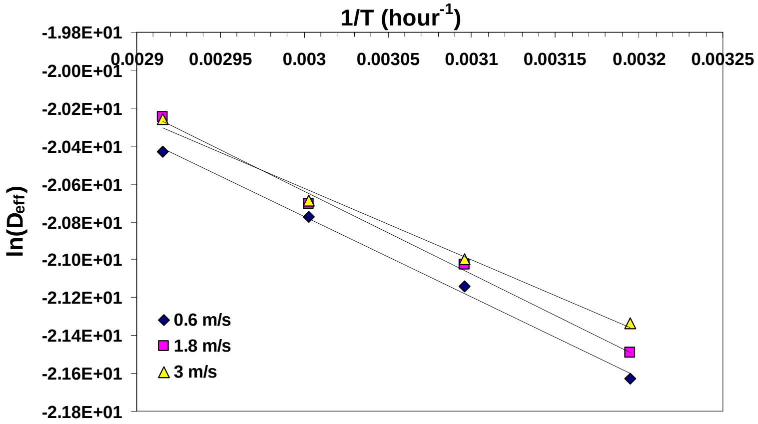

Figure 4 – ln(D_{eff}) against 1/T for different air velocities levels of cantaloupe slices drying

Table 4 - Activation energy of cantaloupe slices and related R^2 values for different drying conditions

Air velocity (m/s)	0.6	1.8	3
E_a (kJ/mol)	30.43	36.23	31.48
R^2	0.9968	0.9946	0.9911
Equation	$\ln(D_{eff}) = -8.01 - \frac{4252.8}{T}$	$\ln(D_{eff}) = -7.56 - \frac{4357.8}{T}$	$\ln(D_{eff}) = -9.27 - \frac{3785.8}{T}$

E_a values against air velocity is depicted in *Fig. 5*. A two degree polynomial model was fitted to the E_a data set as follow:

$$E_a = -3.67v^2 + 13.64v + 23.56 \quad R^2 = 1 \qquad (7)$$

A good correlation is established between E_a and air velocity. Maximum value of E_a obtained at air velocity of 1.8 m/s (*Fig. 5*). Similar results have been reported about berberies fruit (Aghbashlo *et al.*, 2008) and grape (Chayjan *et al.*, 2011b).

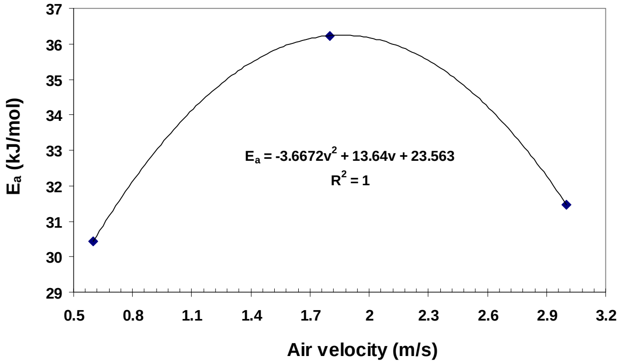

Figure 5 - Effect of air velocity on activation energy of cantaloupe slices

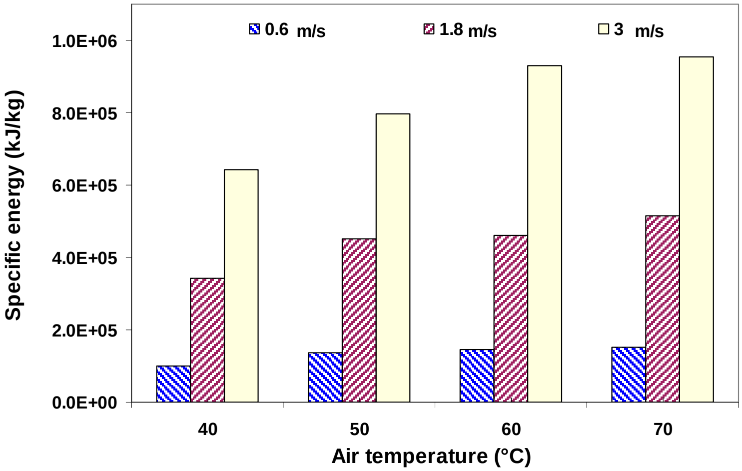

Figure 6 - Effect of air temperature and air velocity on specific energy consumption of cantaloupe slices drying

Specific energy consumption. Specific energy consumption (*SEC*) of cantaloupe slices was calculated using Eq. (6). *Fig. 6* shows the *SEC* values for cantaloupe slices drying under different drying conditions. Results showed that the *SEC* was increased as the air temperature was increased. Also increasing air velocity causes a intensive increase in *SEC*. Minimum *SEC* (1.01×10^5 kJ/kg) was achieved in 0.6 m/s and input air temperature of 40°C. Also maximum *SEC* (9.55×10^5 kJ/kg) was calculated in air velocity of 3 m/s and input air temperature 70°C. Results approved that applying of upper air velocity and input air temperature lead to intensive increase in *SEC*. In other words, high temperature level and air velocity causes an increase in energy consumption rate. Increasing air velocity causes more energy transfer rate to cantaloupe slices, but energy loss was also increased. Similar patterns have been addressed in drying of paddy (Khoshtaghaza *et al.,* 2007) and berberies fruit (Aghbashlo *et al.,* 2008). Three polynomial models were fitted to predict the *SEC* values in different air velocities as follow:

$$SEC = -78.54T^2 + 10177T - 17867 \quad R^2 = 0.9770 \quad (0.6\ m/s) \quad (8)$$

$$SEC = -141.1T^2 + 20769T - 25526 \quad R^2 = 0.9350 \quad (1.8\ m/s) \quad (9)$$

$$SEC = -320.7T^2 + 45935T - 68455 \quad R^2 = 0.9940 \quad (3\ m/s) \quad (10)$$

CONCLUSIONS

Results of cantaloupe slices drying in different air velocities and input air temperature indicated that the effective moisture diffusivity varied between 4.05×10^{-10} and 1.61×10^{-9} m^2/s. Moreover, increase in input air temperature for each air velocity level caused an intensive increase in D_{eff}, while increase in input air velocity in each air temperature had no significant effect on D_{eff}. Activation energy of cantaloupe slices varied between 30.43 and 36.23 kJ/mol. Finally, specific energy consumption obtained for cantaloupe slices drying between 1.01×10^5 and 9.55×10^5 kJ/kg.

REFERENCES

Aghbashlo M, Kianmehr M. H., Samimi-Akhijahani H., 2008 - Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (*Berberidaceae*). Energy Conversion and Management, 49, 2865–2871.

Arabhosseini A., Huisman W., Van Boxtel A., Muller J., 2009 - Modeling of thin layer drying of tarragon (*Artemisia dracunculus* L.). Industrial crops and products, 29, 53–59.

Arumuganathan T., Manikantan M. R., Rai R. D., Anandakumar, S., Khare V., 2009 - Mathematical modeling of drying kinetics of milky mushroom in a fluidized bed dryer. International Agrophysics, 23, 1-7.

Babalis S., Belessiotis V. G., 2004 - Influence of drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. Journal of Food Engineering, 65, 449–58.

Bakal S. B., Gedam K. H., Sharma G. P., 2010 - Drying characteristics and kinetics of fluidized bed dried potato. Agricultural and Food Science, 19, 127-135.

Behbahani M., 2005 - Genetic diversity among Iranian melons (*Cucumis melo* L.) via SSR markers. MS Thesis, Boualisina University, Hamedan, Iran.

Chayjan R. A., Parian J. A., Esna-Ashari M., 2011a - Modeling of moisture diffusivity, activation energy and specific energy consumption of high moisture corn in a fixed and fluidized bed convective dryer. Spanish Journal of Agricultural Research, 9(1), 28- 40.

Chayjan R. A., Peyman M. H., Esna-Ashari M., Salari K., 2011b - Influence of drying conditions on diffusivity, energy and color of seedless grape after dipping process. Australian Journal of Crop Science, 5(1), 96-103.

Doymaz I., 2007 - The kinetics of forced convective air-drying of pumpkin slices. Journal of Food Engineering, 79, 243–248.

Erenturk S., Erenturk K., 2007 - Comparison of genetic algorithm and neural network approaches for the drying process of carrot. Journal of Food Engineering, 78, 905–912.

FAOSTAT, 2009 - FAO statistics data base on the world wide web. http://faostat.fao.org. Last accessed May 2011.

Gazor H. R., 2009 - Modeling drying kinetics of canola in fluidized bed dryer. Iranian Journal of Biosystems Engineering, 40(2), 175-184. (in Farsi)

Goyal R. K., Kingsly A. R. P., Manikantan M. R., Ilyas S. M., 2007 - Mathematical modeling of thin layer drying kinetics of plum in a tunnel dryer. Journal of Food Engineering, 79, 176–180.

Hashemi G., Mowla D., Kazemeini M., 2009 - Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. Journal of Food Engineering, 92, 331–338.

Kaleta A., Górnicki K., 2010 - Some remarks on evaluation of drying models of red beet particles. Energy Conversion and Management, 51, 2967–2978.

Khoshtaghaza M. H., Sadeghi M., Amiri Chayjan R., 2007 - Study of rough rice drying process in fixed and fluidized bed conditions. Journal of Agricultural Science and Natural Resource, 14(2), 127-137. (in Farsi)

Kingsly A. R. P., Goyal R. K., Manikantan M. R., Ilyas, S. M., 2007 - Effects of pretreatments and drying air temperature on drying behaviour of peach slice. International Journal of Food Science and Technology, 42, 65-69.

Sacilik K., 2007 - Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (*Cucurbita pepo* L.). Journal of Food Engineering, 79, 23–30.

Zhang Q., Yang S. X., Mittal G. S., Yi S., 2002 - Prediction of performance indices and optimal parameters of rough rice drying using neural network. Biosystems Engineering, 83(3), 281-290.