Modeling of vacuum-infrared drying of pistachios

Ahmad Kouchakzadeh, Kourosh Haghighi

(*Ilam University, Ilam, Islamic Republic of IRAN, Pazoohesh Avenue, Ilam*)

Abstract: The vacuum-infrared drying of two varieties of Iranian pistachios (Khany and Abasali) was performed in a laboratory scale vacuum dryer, which was developed for this purpose. A non-linear regression Logarithmic model represents good agreement with experimental data with coefficient of determination and mean square of deviation as 0.9942 and 2.035×10^{-5} for Khany variety and 0.9951 and 2.365×10^{-5} for Abasali pistachios respectively. Using combined vacuum infrared radiation to drying pistachios has a number of advantages. Pistachios can be dried approximately eight to ten times faster than dryers that rely on conventional convection and conduction processes only; drying at near room temperatures is the most economical way and it seems the quality in the drying process is enhanced.

Keywords: Mathematical modeling, vacuum-infrared drying, pistachios

Citation: Ahmad Kouchakzadeh, Kourosh Haghighi. 2011. Modeling of vacuum-infrared drying of pistachios. Agric Eng Int: CIGR Journal, 13(3): —.

1 Introduction

In the recent years, the production of pistachio (Pistachio Vera l) in central Iran has increased dramatically so that it is now about 380000 hectares and 350000 tons of pistachio production annually. Iran is the most important pistachio exporter (DIA, 2008).

Pistachio nuts grow in grape-like clusters and have outer skin with the name of hull, which encase each nut. When the hull ripes and turns rosy and the inside shell splits naturally, it indicates the nut is ready to be harvested. Harvest usually begins in early September and continues for four to six weeks. Iranian pistachios are mechanically shaken from the tree (in under a minute) or by hand at a low rate of speed and fall directly onto a catching frame. During the processing plant workers use machines to remove the hull and dry the nuts within 12 to 24 hours after harvest, ensuring the highest quality standards. Technological advances continue to improve sorting and grading techniques. For example, electric eyes detect any dark-stained shells and blow them away by a jet of air. Further processing may include roasting, salting and dying the nut red to meet consumer demand. More than 90 percent of the pistachios sold are roasted and salted. Figure 1 shows the schematic diagram of these processes. (Kouchakzadeh and Tavakoli, 2009)

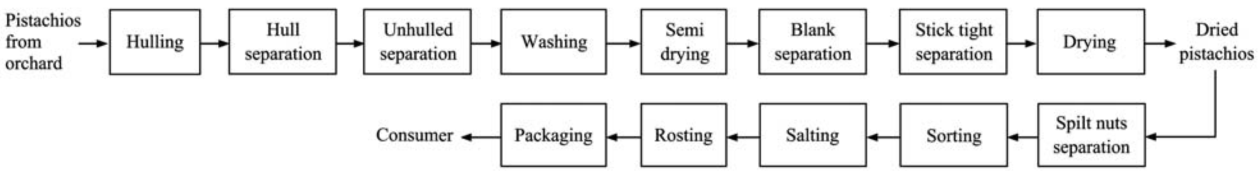

Figure 1 Schematic diagram of postharvest processes of pistachios

The pistachios moisture at harvesting time is about 40 to 50% (dry basis (d.b.)) according to date and climatic location. However, for storage and consumption pistachios need to be dried to moisture content from 5% to 7%. Rate of drying pistachios in free air is slow and

Received date: 2011- **Accepted date:** 2011-
Ahmad Kouchakzadeh, Assistant professor of Agri Machinery Engineering, Email: akouchakzadeh@mail.ilam.ac.ir; Phone: 00989124532128; Fax: 00988412227015.
Kourosh Haghighi, MSc Student.

needs 2 or 3 days period that produce conditions in with fungus growth. So pistachios dryers are needed where pistachios in bulk expose hot air at temperatures 50 to 93℃ for 3 to 8 hours. Huge amount of fossil fuel is being burned annually by these dryers (Kader et al., 1979). During the drying process, nuts can undergo undesirable reactions (especially rancidity) which cause degradation of quality, because of the odd colors and flavors formed. The pistachio is a kind of nut with high lipid content and very rich in unsaturated fatty acids, which makes pistachio nuts very sensitive product owing to rancidity (Dennis and Singh., 1997). In comparison with other food products, studies on the drying of pistachio nuts are very limited. Drying temperature affects the sensory attributes of pistachio nuts and its roasted flavor increases during high temperatures drying (116–138℃). Drying to appropriate moisture content (5%–7% (d.b.)) is an important factor insuring good quality. Nuts dried to 5% (d.b.) moisture content are rated higher in crispness and sweetness, and lower in bitterness and rancidity than those dried to 7% or 12% (d.b.) moisture content (Kouchakzadeh and Shafeei, 2010).

The drying of pistachio nuts is a great problem because of the possibility of loss of nutritional value and enzymatic activity during dehydration. A number of workers have developed empirical correlations to predict drying rates of grain sorghum, rice and potatoes (Eren and Kaymak-Ertekin, 2007). Relatively little research has been performed on the drying of pistachio nuts compared to other food materials. There are many published mathematical models available for estimating the simultaneous heat and moisture transfer in drying of food materials (Doymaz, 2005, Hacıhafızoglu, Cihan and Kahveci, 2008, Yaldiz, Ertekin and Uzan, 2001) .

Vacuum-infrared drying is an addition in the existing drying techniques, compared with convective air-drying (cabinet, flat bed, tunnel), spray, microwave, foam mat and freeze-drying. A vacuum-infrared dryer is a type of dryer that can heat materials, typically foodstuff, to not high-temperatures and carry out processes such as drying and heat treatment with high consistency and low contamination. In a vacuum-infrared dryer, the product in the oven is surrounded by a vacuum while infrared radiation heating them. The absence of air and other gases prevents heat transfer with the product through convection. Uniform temperatures, temperature can be controlled within a small area, low contamination of the product by oxygen and other gases and quick cooling of product are some of the benefits of a vacuum dryer. Heating foodstuff to high temperatures normally causes rapid oxidation, which is undesirable. A vacuum dryer removes the oxygen and prevents this from happening. Drying under vacuum is generally performed at low temperature, so that water evaporates at low temperature.

Infrared radiation is applied to several dryers because it has advantages of increased drying efficiency and space saving (Ratti and Mujumdar, 1995). The use of infrared radiation technology in dehydrated foods has several advantages as follows: decreased drying time, high-energy efficiency, high quality product, uniform temperature in the product and reduced necessity for airflow across the product. Several researchers have used infrared drying technique successfully to dry many food products, e.g., potato (Afzal and Abe, 1998), barley (Afzal and Abe, 2000) and rice (Abe and Afzal, 1997). Since most foods are heat sensitive in nature, it is desirable to be able to dry these products at low temperature to preserve the quality. Several researchers have indeed combined the advantages of infrared drying with that of vacuum drying to dry several food products. Liu et al. tested a vacuum belt drying technique for drying natural herb and founded the logarithmic drying model (Liu et al., 2009). Mongpraneet et al. examined the drying behavior of the leaf parts of welsh onion undergoing combined far infrared and vacuum drying. The results showed that the radiation intensity levels dramatically influenced the drying rate and the dried product qualities (Mongpraneet, Abe and Tsurusaki, 2002). They later determined the energy consumption in infrared drying of onion. From their experiments, less than half of the energy input was utilized for evaporating water from the onion (Mongpraneet Abe and Tsurusaki, 2004).

Pistachio is a high-moisture commodity having as high as 50%-60% moisture content and vacuum drying has not yet been attempted. The objective of the present work is to study the effect of vacuum heating on pistachios drying kinetics. Additionally, the present work enables the low temperatures drying of pistachio available with vacuum-infrared drying but with a more flavorful taste and a more traditional texture and surface coloring.

2 Materials and methods

In this study, Khany and Abasali, two varieties of Iranian pistachios, were used for consideration of drying kinetics of pistachio in vacuum-infrared drying. The samples obtained from an orchard in Iran, Kerman province. The unshelled pistachios were used in this research.

The initial moisture content of samples was determined by oven drying at temperature of 130℃ for 6 hours according to a standard method ASAE (ASAE, 2005). About 150 grams of pistachios was placed in an oven, its final weight was taken, and the difference in weight was taken as water loss and expressed as grams water per grams dry matter. The values of initial moisture content of Khany pistachios and Abasali pistachios were 61.2%(db) and 53.8%(db), respectively.

A monolayer of pistachio was placed on plate of digital weight on vacuum dryer then the variation of weight of pistachio was recorded and moisture content was determined for any time. Drying temperatures were controlled at 25, 30, 35 and 40℃ and the basic vacuum was kept at a value of 50 mbar. After the temperature and vacuum keeping constant, the measuring was started.

2.1 Experimental procedure

The drying was performed in a vacuum infrared oven. The construction and operation is shown in Figure 2. The dryer consists of a vacuum drying oven (Model VO 400 Memmert Co, Germany) and an electronic weight apparatus (E-TRONIX Co, Poland) for measurements of inside vacuum oven. The objective was to adapt electronic weight to operating inside vacuum oven. Data were transferred wirelessly to computer and IR communication is used for data wireless transmission to computer. IR transmitter is outside electronic weight placed (inside vacuum oven), while IR receiver is outside vacuum oven placed. Additionally, electronic weight has been installed with temperature sensor. Electronic weight transmits current weight, temperature and number of measurements to computer. Data are stored in computer and saved in file. Data are transmitted every 1 or 10 minutes, depending on switch position. Electronic weight has battery power supply and an accuracy 0.01 g measured weight of pistachios.

The vacuum was controlled by digital electronic solenoid valves with the adjustment range from 10 to 1100 mbar and resolution 1 mbar digital display of actual pressure and drying temperature was controlled by 2 high-grade platinum temperature sensors pt100 which were built in the top of oven (Figure 2) with the sensitivity of ±1℃.

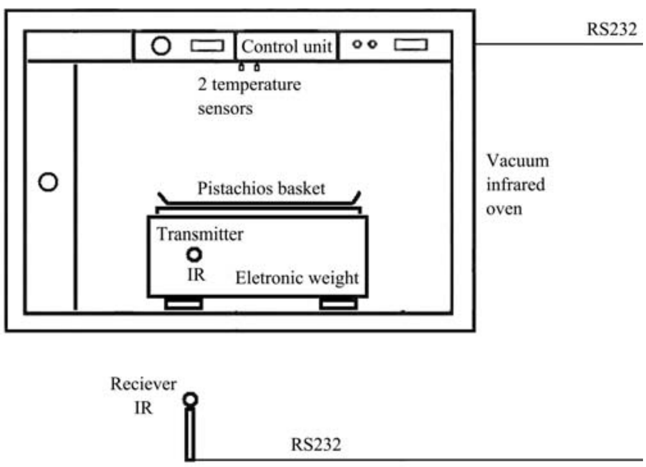

Figure 1 Schematic diagram of laboratory vacuum-infrared dryer

2.2 Theoretical methods:

Moisture ratio (M_R) estimated from equation (1):

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

Where M, M_0 and M_e are present, initial and dynamic equilibrium moisture contents.

The moisture ratio may be simplified to M/M_0 instead of $(M-M_e)/(M_0-M_e)$ because of the value of dynamic equilibrium moisture content M_e is very small compare to M and M_0 (Jayas et al., 1991, Mongpraneet Abe and Tsurusaki, 2002, Liu et al., 2009).

Drying curves were fitted with 6 models which were attempted by several researchers such as: Jayas et al. (1991), Kashaninejad et al. (2007), Jain and Pathare (2007).

These models which were used to describe the thin layer drying of biological materials are Newton, Page, Henderson Pabis, Logarithmic, Two term and Wang and Sing models and they are represented in equations (2) to (7) respectively:

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

$$M_R = \exp(-kt^n) \quad (3)$$

$$M_R = a\exp(-kt) \quad (4)$$

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

$$M_R = a\exp(-k_0 t) + b\exp(-k_1 t) \quad (6)$$

$$M_R = 1 + at + bt^2 \quad (7)$$

The acceptability of models was determined by the coefficient of determination R^2, and the reduced value of mean square of deviation χ^2. The reduced chi-square can be calculated as (Doymaz, 2005):

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

Where $MR_{\exp,i}$ is the experimental moisture ratio; $MR_{pre,i}$ is predicted moisture ratio; N is number of observation, and n is number of constants. Non-linear regression analyses were carried out by using statistical computer program.

3 Results and discussion

3.1 Variation of moisture content

The initial moisture content of two varieties of pistachios, Abasali and Khany, were 53.8% (db) and 61.2% (db) respectively. The moisture content of products as a function of drying time is presented in Figure 3 and Figure 4. As shown in figures, the drying rates have two falling rate period, which are different from that reported for rice, grain sorghum, apricot, potato drying and onion (Tsamo et al., 2005). This may be due to the capillary property and cell structure of the pistachio nuts as indicated by the rate of drying, which is not constant.

During the first period, the surface of product behaves as a surface of free water. The rate of moisture content removal from the surface is dependent on condition of places that drying is occurred, while in second stage the moisture migration from the inter layers of products to surface. The second stage is dependent on the rate of diffusion of moisture from within the product to the surface and also moisture removal from the surface. Both the external factors and internal mechanism controlling the drying process in two main rate regimes are important in determining the overall drying rate of products (Ekechukwu, 1999).

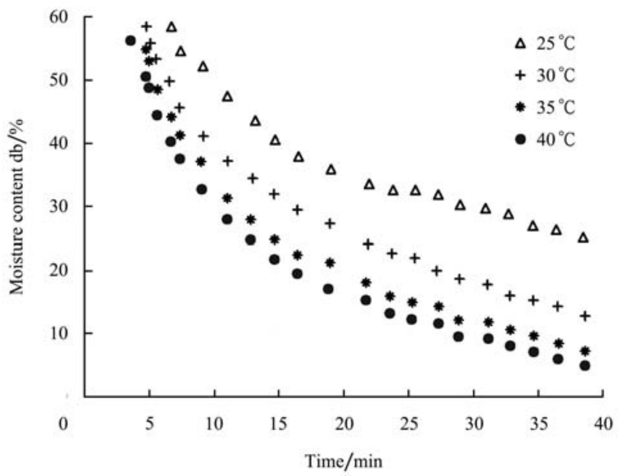

Figure 3 Moisture content of Khany pistachios versus drying time at vacuum 50 mbar

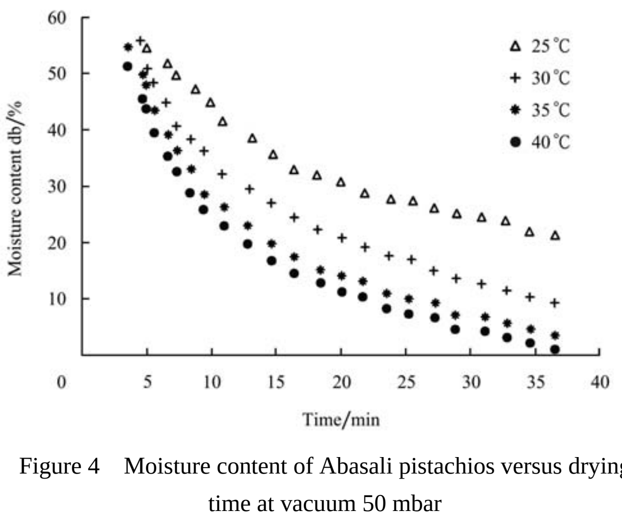

Figure 4 Moisture content of Abasali pistachios versus drying time at vacuum 50 mbar

3.2 Mathematical modeling

Table 1 and Table 2 show the drying constants and the values of R^2 and χ^2. Figure 5 and Figure 6 present the variation of moisture ratio from six drying model versus drying time for two varieties of pistachios. These models were estimated by using the ratio of *MR*. Table 1 show that R^2=0.9942, χ^2=2.035×10^{-5} for Khany variety and Table 2 show that R^2=0.9951, χ^2=2.365×10^{-5}, for Abasali pistachio from Logarithmic model. Our results showed that the Logarithmic model has a good agreement with the experimental data and give the best results for two varieties of pistachios. According to R^2 close to one and lower χ^2, the Logarithmic model was selected to represent the vacuum drying behavior of pistachios. Figure 5 and Figure 6 show the graph of six models for Abasali and Khany pistachios. No researches about vacuum-infrared mathematical modeling in drying of agricultural products were found. Kouchakzadeh and Shafeei showed that the Page model was adapted to microwave–convective drying of pistachios (Kouchakzadeh and Shafeei, 2010). Kashaninejad et al. (2007) showed that the Page model was most suitable to describing the drying behavior of the pistachio nuts by convective heating (Kashaninejad et al., 2007) and Midilli et al, showed that the logarithmic model is the best model for prediction of behavior of thin layer drying of pistachio by using solar energy (Midilli et al., 2003). Our results show that the Page models have a lower agreement than Logarithmic model.

Table 1 Modeling of moisture ratio according to drying time for Khany pistachios

Model	Parameters	Value	R^2	χ^2
Newton	*k*	0.0846965	0.9440	4.663×10^{-5}
Page	*k*	0.0651915	0.9612	3.205×10^{-5}
	n	0.7012269		
Henderson pabis	*A*	0.5005668	0.9303	4.187×10^{-5}
	k	0.6975971		
Logarithmic	*a*	0.5582711	0.9942	2.035×10^{-5}
	k	1.9058055		
	c	-0.0125063		
Two term	*a*	0.0852833	0.9701	3.112×10^{-5}
	k_0	-0.1010515		
	b	0.1070034		
	k_1	1.0015211		
Wang and sing model	*a*	-0.0654565	0.9692	3.989×10^{-5}
	b	0.0002233		

Table 2 Modeling of moisture ratio according to drying time for Abasali pistachios

Model	Parameters	Value	R^2	χ^2
Newton	*k*	0.0838866	0.9330	3.664×10^{-5}
Page	*k*	0.0061532	0.9712	3.515×10^{-5}
	n	1.0117013		
Henderson pabis	*A*	0.5907841	0.9413	3.887×10^{-5}
	k	0.0785006		
Logarithmic	*a*	0.8327309	0.9951	2.365×10^{-5}
	k	0.3705625		
	c	-0.2765109		
Two term	*a*	0.2955281	0.9685	3.992×10^{-5}
	k_0	0.7627085		
	b	0.2955681		
	k_1	0.0785772		
Wang and sing model	*a*	-0.0606745	0.9702	4.013×10^{-5}
	b	0.0001676		

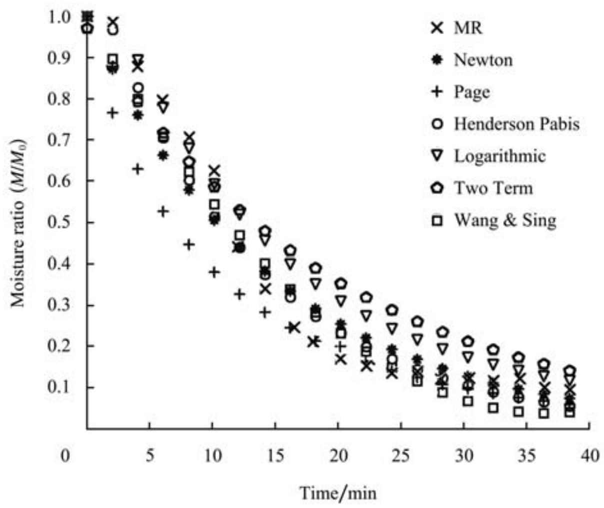

Figure 5 Variation of moisture ratios from different drying models versus drying time for Khany pistachios samples in vacuum drying process

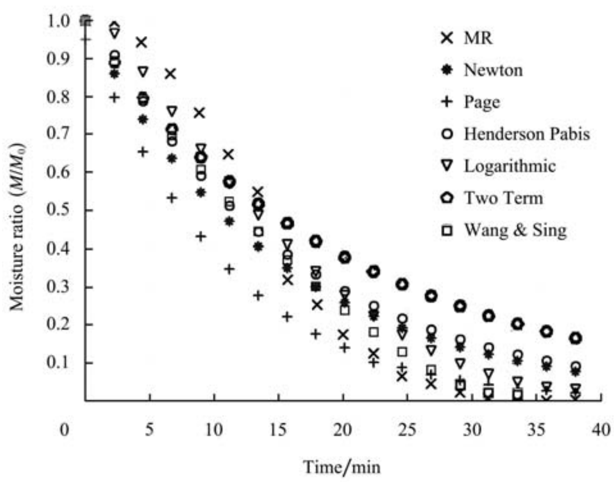

Figure 6 Variation of moisture ratios from different drying models versus drying time for Abasali pistachios samples in vacuum drying process

4 Conclusions

The vacuum-infrared drying processes of two varieties of pistachios have two falling rate period. According to obtained results from models evaluation the Logarithmic model could be described the behavior of vacuum drying of two varieties of pistachio on the basis of statistical parameters such as R^2 and χ^2.

Using combined vacuum-infrared radiation to drying pistachios has a number of advantages. Pistachios can be dried approximately eight to ten times faster than dryers that rely on conventional convection and conduction processes only. Drying at near room temperatures is the most economical way and it seems the quality in the drying process is enhanced.

References

Abe, T. and T. M. Afzal. 1997. Thin-layer infrared radiation drying of rough rice. Journal of Agricultural Engineering Research, 67(4): 289-297.

Afzal, T. M.and T. Abe. 1998. Diffusion in potato during far infrared radiation drying. Journal of Food Engineering, 37(4):353-365.

Afzal, T.M. and T. Abe. 2000. Simulation of moisture changes in barley during far infrared radiation drying. Computer & Electronic in Agriculture, 26(2): 137-145.

ASAE. 2005. Standard for measurement of moisture in grin and seed. Agricultural Engineers Yearbook , 564-565.

DIA. Data and Information Administration. 2008. Agricultural Statistic Collection; Ministry of Jahad Agriculture of Iran, Dept. of Budget and Programming, Tehran, Iran.

Dennis, R. H. and R. P. Singh. 1997. Food process engineering. Avi Publishing House, Westport UK. 99-101. ISBN: 0-870-55380-1

Doymaz, I. 2005. Drying Characteristics and kinetics of okra. Journal of Food Engineering, 69(3): 275-279.

Ekechukwu, O. V. 1999. Review of solar energy drying systems I: An overview of drying principles and theory. Energy Conversion and Management, 40(6): 593-613.

Eren, I. and F. Kaymak-Ertekin. 2007. Optimization of osmotic dehydration of potato using response surface methodology. Journal of Food Engineering, 79(1): 344-352.

Hacıhafızoglu, O., S. Cihan and K. Kahveci. 2008. Mathematical modeling of drying of thin layer rough rice. Food and Bioproducts Processing, 86(4): 268-275

Jain, D and P. B. Pathare. 2007. Study the drying kinetics of open sun drying of fish. Journal of Food Engineering, 78(4): 1315-1319.

Jayas, D. S., S. Cenkowski, S. Pabis and W. E. Muir. 1991. Review of thin layer drying and wetting equations. Drying Technology, 9(3): 551-588.

Kader, A. A.; J. M. Labivitch, F. G. Mitchell and N. F. Sommer. 1979. Quality and safety of pistachio nuts as influenced by postharvest handling procedure. The Pistachio Association Annual Report, 45–56.

Kashaninejad, M., A. Mortazavi, A. Safekordi and L. G. Tabil. 2007. Thin-layer drying characteristics and modeling of pistachio nuts. Journal of Food Engineering, 78(1): 98–108.

Kouchakzadeh, A. and S. Shafeei. 2010. Modeling of microwave-convective drying of pistachios. Energy Conversation and Management, 51(10): 2012-2015.

Kouchakzadeh, A. and T. Tavakoli. 2009. The Effect of Moisture and Temperature on Thermophysical Properties of Iranian Pistachios. World Applied sciences Journal, 7(12): 1552-1558.

Liu X., Z. Qiu, L. Wang, Y. Cheng, H. Qu and Y. Chen. 2009. Mathematical modeling for thin layer vacuum belt drying of Panax notoginseng extract. Energy Conversion and Management, 50(4): 928–932.

Midilli, A. and H. Kucuk. 2003. Mathematical Modelling of thin layer drying of pistachio by using solar energy. Energy Conversion and Management, 44(7): 1111-1122.

Mongpraneet, S., T. Abe, and T. Tsurusaki. 2002. Accelerated drying of welsh onion by far infrared radiation under vacuum conditions. Journal of Food Engineering, 55(2): 147-156.

Mongpraneet, S, T. Abe and T. Tsurusaki. 2004. Kinematic Model for a far infrared vacuum dryer. Drying Technology 22(7): 1675-1693.

Ratti, C., and A. S. Mujumdar. 1995. Infrared drying Handbook of Industrial Drying. Marcel Dekker Inc. New York.

Tsamo, C. V. P., A. F. Bilame, R. Ndjouenkeu and Y. J. Nono. 2005. Study of material transfer during osmotic dehydration of onion slices and tomato fruits. LWT - Food Science and Technology, 38(5): 495-500.

Yaldiz, O., C. Ertekin and H. E. Uzan. 2001. Mathematical modeling of thin layer solar drying of sultana grapes. Energy, 26(5): 457-465.