Modeling of ultrasonic-convective drying of pistachios

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Abstract: The combination of high power ultrasound and convective air for drying of pistachios (Akbari variety) was performed in a laboratory scale ultrasonic dryer, which was constructed for this purpose. The drying rate curves showed first rapid decrease and then very little reduction in moisture ratio observed with the increase of drying time. A non-linear regression logarithmic model represented good agreement with experimental data with coefficient of determination and mean square of deviation as 0.9885 and 4.188×10^{-5} for 150W and 0.9890 and 1.639×10^{-5} or 300 W acoustic power respectively. In fact, at two ultrasonic powers, the mathematical drying models were similar.

Keywords: ultrasonic-convective drying; modeling; pistachios

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1 Introduction

Pistachio is the most important agricultural crop cultivated in Iran's tropical region. Pistachio export earnings are the largest among non-petroleum Iranian export industries. Pistachio nuts grow in grape-like clusters and have outer skin with the name of hull, which encase each nut. When the hull ripens, the inside shell splits naturally, which indicates the nut is ready to be harvested. Harvest of pistachios usually begins in September and continues for four to six weeks (Kouchakzadeh and Haghighi, 2011). Iranian pistachios are mechanically shaken from the tree (in less than a minute) or by hand at a low rate of speed and fall directly onto a catching frame. At the processing plant workers use machines to remove the hull and dry the nut within 12 h to 24 h 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 in a jet of air. Further processing may include roasting, salting and dying the nut red to meet consumers' demand. More than 90% of the pistachios sold are roasted and salted (Kouchakzadeh and Tavakoli, 2011).

The pistachios moisture at harvesting time is more than 50% (dry basis (d.b.)) according to date of harvest and climatic location. However, for storage and consumption pistachios need to be dried to about 5% to 7%. Rate of drying pistachios in free air is slowly and needs 2 d or 3 d that produce conditions for fungus growth. So pistachios dryers are needed where pistachios are to be dried in bulk in exposed hot air at temperatures 50℃ to 93℃ for 3 h to 8 h. Huge amount of fossil fuels is being burned annually in these dryers (Kouchakzadeh and Shafeei, 2010). During the long 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 nut with high lipid content and very rich in unsaturated fatty acids, which makes pistachio nuts very sensitive 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 drying

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temperatures (116–138℃). Drying to proper moisture content (5%–7% (d.b.)) is an important factor to ensure good quality. Nuts dried to 5% (d.b.) moisture are rated higher in crispness, and sweetness and lower in bitterness and rancidity than those dried to 7% or 12% (d.b.) moisture (Kader et al., 1979).

The drying of pistachio nut is a great problem because of possible 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. Relatively little research has been performed on the drying of pistachio nut 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 such as: dehydration of potato (Eren and Kaymak-Ertekin, 2007), drying of sultana grapes (Yaldiz et al., 2001) and equations of thin layer drying of many food stuff (Jayas et al., 1991).

Conventional dehydration methods based on hot air drying are widely used but they can deteriorate the quality of the final product. Thus, undesired food flavor, color composition, vitamin degradation and loss of essential amino acids may be produced (Jarayaman and Gupta, 1992, Mujamdar and Menom, 1995).

Among emergent new technologies, ultrasonic dehydration is very promising because the effects of power ultrasound are more significant at low temperature (at (4±1)℃) that reduces the probability of food degradation (Gallego, 1998, Garcia-Pérez et al., 2007). Also, ultrasound permits the removal of moisture content from solids without producing a liquid phase change. Drying heat-sensitive food materials by power ultrasound is one example of the potential use of ultrasound in the food industry. When a high-intensity ultrasonic wave is directed to the material to be dried, it travels through the solid medium causing a rapid series of alternative compressions and expansions, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect). The forces involved by this mechanical mechanism can be higher than surface tension that maintains the moisture inside the capillaries of the material creating microscopic channels that may make the moisture removal easier. In addition, ultrasound produces cavitations that may be beneficial for the removal of the strongly attached moisture. Other effects to be considered are the variation of viscosity, surface tension and the deformation of the porous solid material. This last effect is responsible for the creation of microscopic channels, reducing the diffusion boundary layer and increasing the convective mass transfer in foodstuff. In the convective-ultrasonic drying method, forced air is supplied to carry away the water vapor, driven from the interior of the food to its surface. To prevent the condensation of the driven moisture on the surface of the food, it is needed to heat the air to increase its moisture carrying capacity (Tarleton and Wakeman, 1998).

In recent years, the researchers have been interested in the application of acoustic energy in food dehydration. The promising results obtained have validated the potential use of ultrasonic vibrations, in direct contact with food samples (Gallego-Juárez et al., 1999).

Pistachio is a high-moisture commodity having as high as 50%–60% moisture and combined convective-ultrasonic drying has not yet been tried. The aim of the present work is to study the effect of ultrasonic heating on pistachios drying kinetics. Additionally, the present work reports the low temperature drying of pistachio with convective-ultrasonic drying.

2 Materials and methods

In this study, Akbari, one of the major varieties of Iranian pistachios was used for consideration of drying kinetics in ultrasonic vibration. The samples obtained from an orchard in Iran, Kerman Province. The unshelled pistachios were used in this research. The initial moisture content of samples were determined by oven drying at temperature of 130℃ for 6h according to a standard method ASABE (ASABE., 2006). About 150 g 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 initial moisture content for pistachios was 58.6% (d.b.). Then layer with 15 cm depth of pistachios was placed on drying chamber of device dryer and every

5min the samples were taken out and variation of weight of pistachio recorded and moisture content were determined for any time.

3 Experimental procedure

The conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy is the basis for ultrasonic device. The active element is the heart of the transducer as it converts the electrical energy to acoustic energy, and vice versa. The active element is basically a piece of polarized material with electrodes attached to two of its opposite faces. When an electric field is applied across the material, the polarized molecules will align themselves with the electric field, resulting in induced dipoles within the molecular or crystal structure of the material. This alignment of molecules will cause the material to change dimensions. This phenomenon is known as the piezoelectric effect. The thickness of the active element is determined by the desired frequency of the transducer. A thin wafer element vibrates with a wavelength that is twice its thickness. Therefore, piezoelectric crystals are cut to a thickness that is 1/2 of the desired radiated wavelength (Welti-Chanes and Velez-Ruiz, 2002).

Figure 1 shows the ultrasonic system used in the experiments. It involves a stainless steel vibrating cylinder (100 mm in internal diameter, 200 mm in height and 1.2 mm in thickness) driven by a piezoelectric composite transducer generating a high-intensity ultrasonic field inside the cylinder as drying chamber. The driving transducer consists of an extensional piezoelectric Bolt-clamped Langevin type transducers (BLT) element (SMBLTD50F20HA) with aluminum body and dimensions: 109 mm × 50 mm × 40 mm, resonant frequency (20±1) kHz and maximum output power 1,000 W made by Steiner & Martins, Inc. USA. Bolt-clamped Langevin type transducers are common vibration sources in high-power ultrasonic applications such as ultrasonic plastic welding, bio diesel mixer transducer, solid separation transducer and high-torque traveling wave ultrasonic motor.

An ultrasound generator, MSG.x00.IX.yF with maximum-pulsed power 3,000 W and carrier frequency range 17.5 kHz to 28.5 kHz made by Mastersonic, Inc., Switzerland was applied during experiments. The LED display indicates the ultrasonic generator power level as a percentage of its maximum power. Generator parameters were automatically controlled through a PC connected to the remote serial (RS485) interface via the optional adaptor box. Drying experiments were carried out with 150 W and 300 W, which were 5% and 10% of maximum-pulsed power of ultrasound generator.

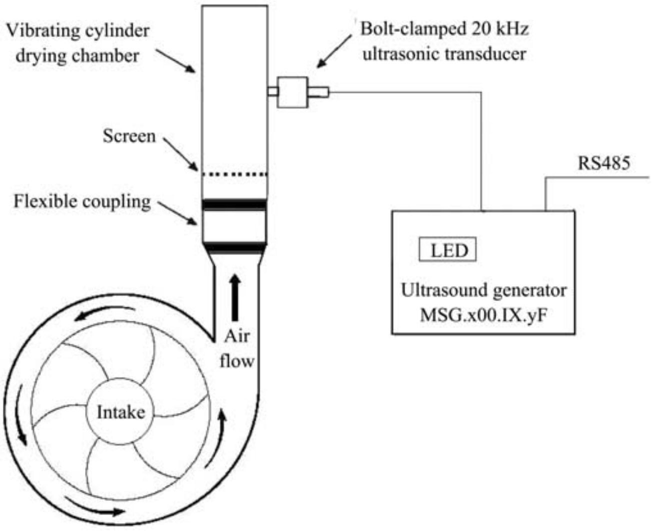

Figure 1 Schematic diagram of test apparatus

Air velocity was controlled by adjusting the size of inlet and was kept at a constant value of 1 m/s with an accuracy of ±0.1 m/s measured with a vane probe anemometer AM-4202 Lutron flowed to the air intake. A fixed room temperature of (25±2)℃ was used during experiments. Sample weight was measured by a laboratory weighing platform (Model AB204, Mettler-Toledo AG, Switzerland) and recorded at regular time intervals (5 min).

4 Theoretical methods

Moisture ratio estimated from Equation (1).

$$M_R = \frac{M - M_e}{M_o - M_e} \qquad (1)$$

where, M, M_o and M_e are present, initial and dynamic equilibrium moisture contents.

The moisture ratio may be simplified to M/M_o instead of $(M - M_e)/(M_o - M_e)$ because of the value of dynamic equilibrium moisture content M_e is very small compared to M and M_o (Kouchakzadeh and Shafeei, 2010, Midilli and Kucuk, 2003, Yaldiz et al., 2001).

Drying curves which were fitted with six moisture ratio models had been attempted by several researchers, such as Jain and Pathare (2007), Jayas et al. (1991), Kashaninejad et al. (2007) and Sharma and Prasad (2005).

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

$$M_R = \exp(-kt) \tag{2}$$

$$M_R = \exp(-kt^n) \tag{3}$$

$$M_R = a\exp(-kt) \tag{4}$$

$$M_R = a\exp(-kt) + c \tag{5}$$

$$M_R = a\exp(-k_0 t) + b\exp(-k_1 t) \tag{6}$$

$$M_R = 1 + at + bt^2 \tag{7}$$

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 χ^2 can be calculated by Kouchakzadeh and Shafeei in 2010.

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

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

5 Results and discussion

The initial moisture of pistachios was 58.6% (d.b.). The moisture content of products as a function of drying time is presented in Figure 2 for two acoustic powers. As is shown in Figure 2, drying rates have two stages, first, the moisture content rapidly reduced and then slowly decreased with the increase in drying time, which was similar to previous report for microwave-convective pistachio drying (Kouchakzadeh and Shafeei, 2010). During the first period, the surface of product behaved as a surface of free water. The rate of moisture content removal from the surface was dependent on the condition of the places that drying occurred, but in second stage the moisture migration was from the inter layers of products to surface. This stage was 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).

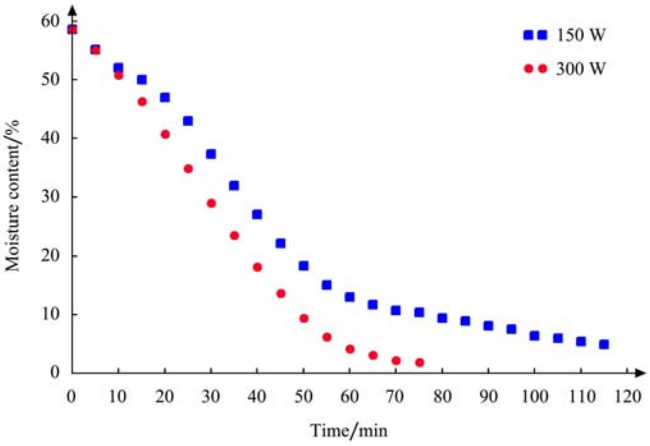

Figure 2 Moisture of pistachios vs. time in ultrasound-convective drying

5.1 Mathematical modeling

Tables 1 and 2 show the drying constants and the values of R^2 and χ^2. Figures 3 and 4 present the variation of moisture ratio from six drying models versus drying time for each acoustic power. These models were estimated by using the ratio of MR. Table 1 shows that $R^2 = 0.9885$, $\chi^2 = 4.188\times10^{-5}$ for 150 W, and Table 2 shows that $R^2 = 0.9890$, $\chi^2 = 1.639\times10^{-5}$ for 300 W power from Logarithmic model. Our results showed that the Logarithmic model has a good agreement with the experimental data and gave the best results for each acoustic power. According to highest R^2 and lowest χ^2, the Logarithmic model was selected to represent ultrasonic drying behavior of pistachios. Figures 3 and 4 show the graph of six models for each power. Midilli and Kucuk (2003) showed that the Logarithmic model is the best model for prediction of behavior of thin layer drying of pistachio by using solar energy. Kouchakzadeh and Shafeei (2010) showed that the Page model was adapted for microwave–convective drying of pistachios, Kashaninejad et al. (2007) showed that the Page model was most suitable for describing the drying behavior of the pistachio nuts by convective heating and our results showed that the Page model have a lower agreement than Logarithmic model for ultrasonic-convective pistachios drying. From Tables 1 and 2, the Logarithmic model had the highest R^2 and lowest χ^2 and thus should have been taken as the acceptable model for this work.

Table 1 Fitting results with different models to the drying at 150 W ultrasound power

Model	Parameters	Value	R^2	χ^2
Newton	k	0.0894	0.9430	6.880×10^{-4}
Page	k	0.0587	0.9790	2.740×10^{-4}
	n	0.8486		
Henderson Pabis	A	0.9167	0.9570	5.750×10^{-4}
	k	0.0734		
Logarithmic	a	0.2260	0.9885	4.188×10^{-5}
	k	0.7838		
	c	0.5270		
Two term	a	0.6980	0.9770	4.590×10^{-5}
	k_0	0.1919		
	b	0.4130		
	k_1	-0.1950		
Wang and Sing model	a	-0.6460	0.9860	5.432×10^{-5}
	b	0.0654		

Table 2 Fitting results with different models to the drying at 300 W ultrasound power

Model	Parameters	Value	R^2	χ^2
Newton	k	0.0619	0.9210	1.114×10^{-3}
Page	k	0.1100	0.9840	9.571×10^{-5}
	n	0.5940		
Henderson Pabis	A	0.9549	0.9620	5.935×10^{-4}
	k	0.0500		
Logarithmic	a	0.2853	0.9890	1.639×10^{-5}
	k	0.3919		
	c	0.7118		
Two term	a	0. 8639	0. 9710	5.689×10^{-4}
	k_0	0.0386		
	b	0. 0987		
	k_1	0. 2296		
Wang and Sing model	a	-0.0937	0.9870	4.835×10^{-4}
	b	0.0086		

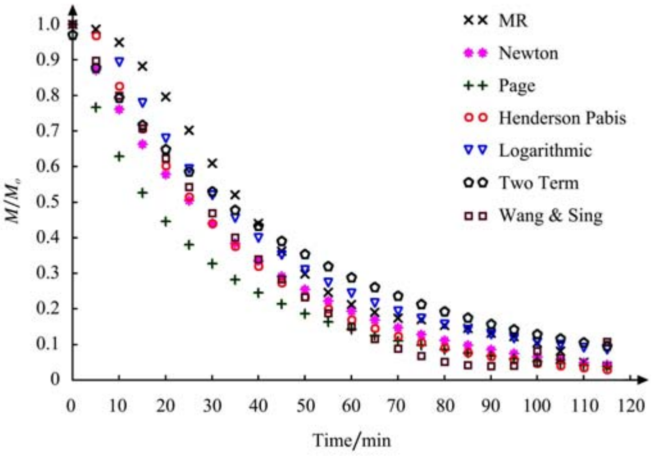

Figure 3 Moisture ratio fitting with the different drying models at ultrasound power of 150 W

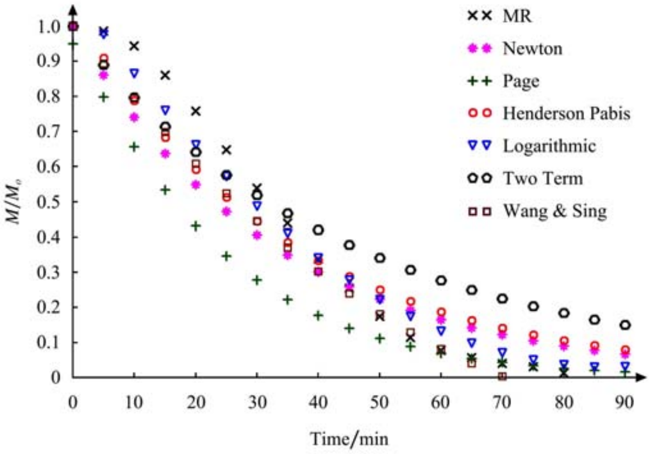

Figure 4 Moisture ratio fitting with the different drying models at ultrasound power of 300 W

6 Conclusion

The ultrasonic-convective drying process of pistachios have more than one falling rate period. According to obtained results from models' evaluation, the Logarithmic model could be used to describe the behavior of each of the two acoustic powers on pistachio drying with the basis of statistical parameters such as R^2 and χ^2.

References

ASABE. 2006. Standard for measurement of moisture in grin and seed. Agricultural Engineers Yearbook of 2006; 564-565.

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

Ekechukwu, O. V. 1999. Review of solar energy drying systems I: An overview of drying principles and theory. *Energy Conversion and Management*, 40(6): 596-613.

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.

Gallego-Juárez, J. A., G. Rodríguez-Corral, J. C. Gálvez-Moraleda, and T. S. Yang. 1999. A new high intensity ultrasonic technology for food dehydration. *Drying Technology*, 17(3): 597-608.

Gallego, J. A. 1998. Some applications of air-borne ultrasound to food processing, in: Malcolm J.W. Povey, and Timoty J. Mason (Eds.), Ultrasonics in Food Processing, Thomson Science, London. pp. 127–143.

Garcia-Pérez, J. V., J. A. Carcel, J. Benedito, and A. Mulet. 2007. Power ultrasound mass transfer enhancement in food drying. *Food and Bioproducts Processing*, 85(3): 247-254.

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.

Jarayaman, K. S., and D. K. Gupta. 1992. Dehydration of fruits and vegetables–recent developments in principles and techniques. *Drying Technology*, 10(1): 1-50.

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

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

Kouchakzadeh, A., and T. Tavakoli. 2011. New practical method for evaluation of a conventional flat plate continuous pistachio dryer. *Energy Conversion and Management*, 52(7): 2735–2740.

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

Mujamdar, A. S., and A. S. Menom. 1995. Drying of solids: Principles, classification and selection of dryers, Handbook of Industrial Drying. 1-40.

Sharma, G. P., and S. Prasad. 2005. Effective moisture diffusivity of garlic cloves undergoing microwave convective drying. *Journal of Food Engineering*, 65(1): 609–617.

Tarleton, E. S., and R. J. Wakeman. 1998. Ultrasonically assisted separation process, in: M.J.W. Povey and T.M. Mason (Eds.), Ultrasounds in Food Processing, Blackie Academic and Professional, Glasgow. pp. 193-218

Welti-Chanes, J., and J. F. Velez-Ruiz. 2002. Transport Phenomena in Food Processing (Food Preservation Technology). CRC Press. pp. 381–474.

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