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Moisture Diffusivity of Five Major Varieties of Iranian Pistachios

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ABSTRACT

The moisture diffusion coefficients of five major varieties of Iranian pistachios (Ahmad_aghayee, Akbari, Badami, Fandoghi and Kaleh_ghoochi) were successfully interpreted and modeled by using Fick's law. The moisture content of the dried nut was increased to 5-7% (d.b.) and drying temperatures (50-90°C) were varied, but the drying air was kept at constant velocity and humidity. The analysis of the data shows no statistically significant difference between the five varieties at the 95.0% confidence level. The diffusivity was estimated from drying rate curves and expressed by exponential relations.

Key words: Fick's law, drying kinetics, pistachio nut

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 produces annually 350000 tons of pistachios. Iran is the most important pistachio exporter (DIA, 2008).

Pistachio nuts grow in grape-like clusters and an outer skin, called the hull, encases each nut. When ripe, the hull turns rosy and the inside shell splits naturally, indicating 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. At the processing plant workers use machines to remove the hull and dry the nut within 12 to 24 h after harvest, ensuring the highest quality standards. Figure 1 shows the schematic diagram of these processes. 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 consumer demand. More than 90% of the pistachios sold are roasted and salted (Kouchakzadeh and Tvakoli, 2010).

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 dry 5 to 7%. Rate of drying pistachios in free air is slowly and needs 2 or 3 days period that produce conditions in with

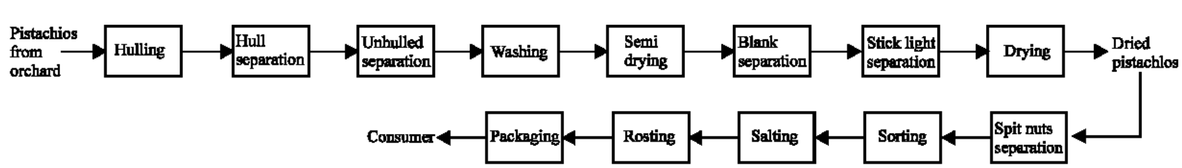

Fig. 1: Schematic diagram of pistachios postharvest processes

fungus growth. So pistachios dryers are needed where pistachios in bulk expose hot air at temperatures 50 to 93°C for 3 to 8 h. Huge amount of fossil fuels is being burned annually in these dryers (Kouchakzadeh and Tvakoli, 2010). 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 nut with high lipid content and very rich in unsaturated fatty acids, this makes pistachio nuts very sensitive product owing to rancidity (Heldman and Sigh, 1981). 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°C). Drying to appropriate moisture content (5-7% (d.b.)) is an important factor insuring 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 (Kouchakzadeh and Shafeei, 2010).

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 (Eren and Kaymak-Ertekin, 2007). 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 (Doymaz and Pala, 2003; Hacihafizoglu *et al*., 2008; Srikiatden and Roberts, 2008; Tsamo *et al*., 2005). The main difficulty is in determining the transport, heat and mass inside the product. It is also difficult to describe the transport of heat and mass inside the product quantitatively due to varying temperature, pressure and structure in different areas. This has an effect on the removal of water from food material. In most research carried out on drying, diffusion is generally accepted to be the main mechanism during the transport of humidity to the surface to be evaporated. The Fick's equation (Brooke *et al*., 1997; Charm, 1978; Heldman and Sigh, 1981) that expresses the diffusion of liquid in a solid can be written:

$$\frac{dm}{dt} = D_{eff}\left[\frac{d^2m}{dr^2} + \frac{jdm}{rdr}\right] \tag{1}$$

where, m is the moisture concentration, t is time, D_{eff} is the diffusion coefficient, r is the radius and j is the coefficient; when j is equal to 0 for an infinitive slab, 1 for a cylinder and 2 for a sphere. The solution to the above equation was given as:

$$\frac{\bar{m} - m_e}{m_0 - m_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(\frac{(-n^2\pi^2 t D_{eff})}{r^2}\right) \tag{2}$$

where, $\bar{m}$ is the average moisture content, m_e is the dynamic equilibrium moisture content at the beginning of falling rates, m_o is initial moisture content, r is the radius of dry material and D_{eff} is the diffusivity coefficient in pistachio nut. The moisture ratio may be simplified to $\bar{m}/m_o$ instead of $(\bar{m} - m_e)/(m_0 - m_e)$ because of the value of dynamic equilibrium moisture content m_e is very small compare to $\bar{m}$ and m_0 (Kouchakzadeh and Shafeei, 2010).

The aim of this study was to investigate the fundamental aspects of the drying of single pistachio nut when fully exposed to air at constant temperature and humidity. From the drying rate, an expression was established concerning moisture diffusivity coefficient.

MATERIALS AND METHODS

Pistachio samples of five major varieties: namely, Ahmad_aghayee, Akbari, Badami, Fandoghi and Kaleh_ghoochi were used in this study (Fig. 2A-E). For a specific variety, pistachios are rejected if they are significantly larger or smaller than the subjective average size. The best quality pistachios graded by experts were obtained from pistachio during harvesting season in September 2009. The samples obtained from an orchard in Iran, Kerman province, Rafsanjan. The unshelled pistachios were used in this research.

The initial moisture content of samples were determined by oven drying at temperature of 130°C for 6 h according to a ASAE standard method (ASAE, 2005).

A single pistachio was placed on plate of digital balance on special dryer then the variation of weight of pistachio recorded and moisture content were determined for any time. The difference in weight was taken as water loss and expressed as grams water per grams dry matter.

Experimental procedure: The drying was done in an oven dryer developed for this purpose. The constructional and operational is shown in Fig. 3. The dryer consists of an electric oven UFE 400-800 MEMMRET GmbH Co, a variable speed fan and a digital force gauge.

Air velocity was kept at a constant value of 1 m sec^{-1} with an accuracy of ±0.1 m sec^{-1} and 65% relative humidity measured with a Vane Probe anemometer plus humidity meter LM-8100 with RS-232 USB computer interface flowed perpendicular to the bed. The samples were dried in a 12cm radius latticed circle basket in oven. A digital force gauge FG-5005 Lutron with RS-232 USB computer interface and an accuracy 0.01 g measured weight of pistachio for any time.

Drying temperature was controlled by 2 high-grade platinum temperature sensor pt100 in 4-wire circuit for long term stability of temperature by fuzzy-supported controller with the sensitivity ±1°C at 50, 60, 70, 80 and 90°C.

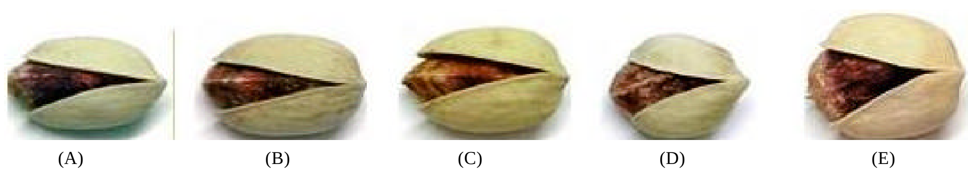

Fig. 2: The five pistachio varieties; (A) Ahmad_aghayee, (B) Akbari, (C) Badami, (D) Fandoghi and (E) Kaleh_ghoochi

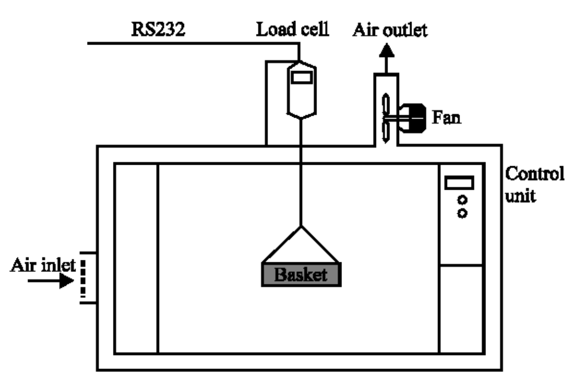

Fig. 3: Schematic diagram of developed dryer

The length distribution of pistachio nut in the range of 1.60 to 1.70 cm was used for the experimental runs. Furthermore, volumetric tests were undertaken to obtain radius estimates of the pistachio nuts. The volume of 100 pistachio nuts was measured. From this, the equivalent spherical radii (3.51-3.90 mm) were calculated. The volume of each pistachio was measured by first weighing it on a laboratory-weighing platform (Model AB204, Mettler-Toledo AG, Switzerland) then measuring the apparent change in the weight of a beaker of water mounted on the same scale, when the pistachio was forced into the water by means of a sinker rod. The scale had a readability of 0.1 mg, repeatability of 0.1 mg, linearity of ±0.2 mg.

RESULTS AND DISCUSSION

Drying runs were conducted at constant air velocity and humidity ratio for different drying temperatures. The analysis of the data shows no statistically significant difference between the five varieties at the 95.0% confidence level. Therefore, the input data for afterward analysis were set to the average of five varieties. The average moisture contents were estimated at temperatures 50, 60, 70, 80 and 90°C as shown in Fig. 4.

The experimental data were presented as a plot of $\log(\bar{m}/m_0)$ vs. time (min) as shown in Fig. 5. From the slope of the curve, the diffusion coefficients were estimated for three falling rate by regression analysis using Statgraphics Centurion XVI software.

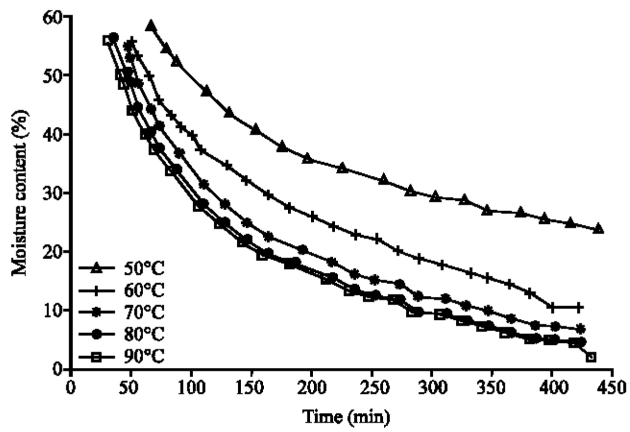

Fig. 4: Drying curve of pistachios at different temperatures (average of 5 varieties)

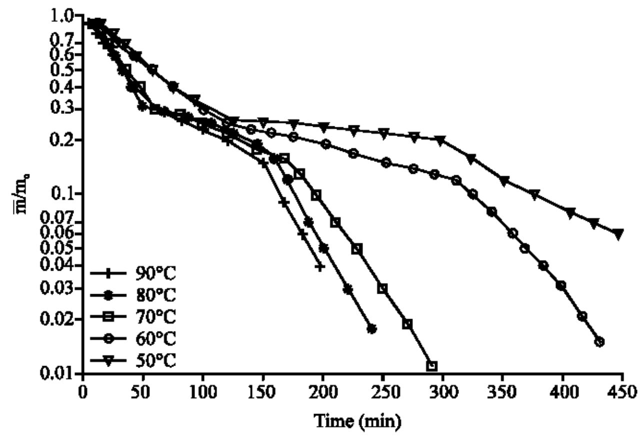

Fig. 5: Plot of $\log(\bar{m}/m_0)$ vs. time at various temperatures

Table 1: Diffusivity coefficients of pistachios calculated at different falling rats $cm^2\ sec^{-1}$

Variety	Temperature (°C)	Calculated radius (mm)	1st falling rate period	2nd falling rate period	3rd falling rate period
Ahmad_aghayee	50	3.55	3.1575×10^{-6}	4.9747×10^{-7}	2.2300×10^{-7}
	60	3.53	3.9525×10^{-6}	4.6642×10^{-7}	1.6947×10^{-7}
	70	3.59	6.2450×10^{-6}	1.3053×10^{-6}	3.4050×10^{-7}
	80	3.51	5.6947×10^{-6}	1.5929×10^{-6}	5.1170×10^{-7}
	90	3.66	6.2675×10^{-6}	1.2262×10^{-6}	6.3970×10^{-7}
Akbari	50	3.55	3.2375×10^{-6}	4.3747×10^{-7}	2.3223×10^{-7}
	60	3.52	3.9325×10^{-6}	4.3034×10^{-7}	1.6897×10^{-7}
	70	3.59	62550×10^{-6}	1.0413×10^{-6}	3.4455×10^{-7}
	80	3.53	5.7094×10^{-6}	1.5529×10^{-6}	5.0171×10^{-7}
	90	3.56	6.2785×10^{-6}	1.2602×10^{-6}	6.3970×10^{-7}
Badami	50	3.55	3.1555×10^{-6}	4.374710^{-7}	2.1123×10^{-7}
	60	3.58	3.5525×10^{-6}	4.3342×10^{-7}	1.7047×10^{-7}
	70	3.59	6.5450×10^{-6}	1.1423×10^{-6}	3.4905×10^{-7}
	80	3.59	5.7947×10^{-6}	1.5529×10^{-6}	5.1314×10^{-7}
	90	3.75	6.6770×10^{-6}	1.2602×10^{-6}	6.3970×10^{-7}
Fandoghi	50	3.68	3.1152×10^{-6}	4.3747×10^{-7}	2.2889×10^{-7}
	60	3.65	3.9925×10^{-6}	4.3342×10^{-7}	1.4117×10^{-7}
	70	3.69	6.2450×10^{-6}	1.0543×10^{-6}	3.5450×10^{-7}
	80	3.63	5.6947×10^{-6}	1.5529×10^{-6}	5.2167×10^{-7}
	90	3.67	6.2675×10^{-6}	1.2602×10^{-6}	6.1497×10^{-7}
Kaleh_ghoochi	50	3.85	3.1575×10^{-6}	4.6747×10^{-7}	2.7530×10^{-7}
	60	3.83	3.9525×10^{-6}	4.3342×10^{-7}	1.7697×10^{-7}
	70	3.85	6.2450×10^{-6}	1.1154×10^{-6}	3.4915×10^{-7}
	80	3.81	5.6747×10^{-6}	1.5329×10^{-6}	5.2696×10^{-7}
	90	3.90	6.6675×10^{-6}	1.6602×10^{-6}	6.3880×10^{-7}

The drying rates have more than one falling rate period, which were 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 nut as indicated by the rate of drying, which was not constant.

The diffusivity for all runs ranged from 1.4117×10^{-7} to 6.67770×10^{-6} $cm^2\ sec^{-1}$ depending on the drying temperature (Table 1). Drying of grain gave values of 0.3×10^{-6} to 1.1×10^{-6} $cm^2\ sec^{-1}$ at 40 to 70°C (Suarez *et al*., 1980), while drying of apricot gave 1×10^{-7} to 3×10^{-7} $cm^2\ sec^{-1}$ at 50 to 80°C (Togrul and Pehlivan, 2003).

Exponential regression equations were determined for the data with R^2>83% as follows:

$$D_{eff} = 1.58455\times10^{-5}\exp(\frac{-77.892}{T}) \quad (3)$$

$$D_{eff} = 2.48528\times10^{-6}\exp(\frac{-53.3394}{T}) \quad (4)$$

$$D_{eff} = 4.13498\times10^{-6}\exp(\frac{-169.592}{T}) \quad (5)$$

The Eq. 3-5 are valid for first falling rate period, second falling rate period and third falling rate period, respectively. Figure 6 shows the results. It was observed that diffusivities in the first

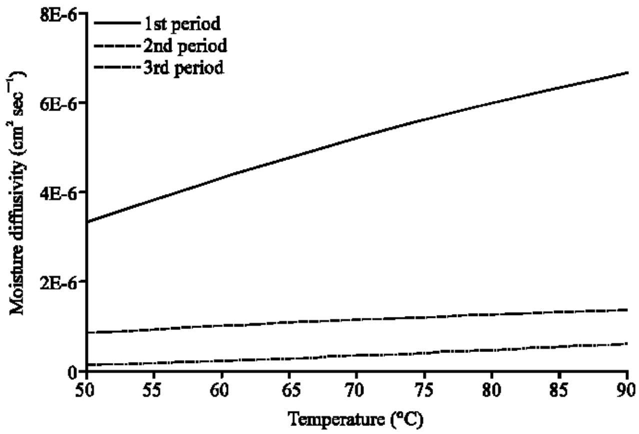

Fig. 6: The effect of temperature on moisture diffusivity of pistachios

drying stages were increased rapidly with high slope vs. temperature but the second and third phases have very similar low-slope curve. This indicates that first falling rate period was highly sensitive to temperature changes.

As can be observed in general from drying curves and diffusivities, at initial drying stages the removal of moisture from the pistachio nut caused high diffusivity. considering the diffusivity value at 50, 60, 70, 80 and 90°C based on applicability of Eq. 2, when most of the monolayer water is removed, the diffusivity is reduced.

CONCLUSION

The air-drying of five varieties of pistachios nut have been investigated. From drying curves at different temperatures, the effective diffusivities of moisture were estimated and an attempt to relate these functions to the way water moves within single pistachio nut was made.

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