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Convective drying of garlic (*Allium sativum* L.): Part I: Drying kinetics, mathematical modeling and change in color

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Abstract

Garlic (*Allium sativum* L.) is an important Allium spice that is a strong source of vitamin C and has antiseptic properties. From an economic point of view, the dried garlic slices are valuable products in Iran. The drying behavior of the garlic slices as a thin layer was investigated in a hot air dryer at the air temperatures of 50, 60 and 70˚C and slice thicknesses of 2, 3 and 4 mm. The effect of these conditions on the quality and appearance of garlic were also investigated. Both the drying air temperature and slice thickness affected the drying rate and time. The sample thickness increasing led to decreasing the drying rate. This reduction would affect the drying energy requirements significantly. In order to derive and select the appropriate drying model, nine mathematical models were fitted to the experimental data. According to the statistical criteria, the Weibull model was found to be adequate for describing the thin layer drying behavior of garlic slices. The final color characteristics values of dried garlic slices such as lightness, yellowness and redness were affected significantly by the air temperature and slice thickness at their studied ranges. Increasing in the both of air temperature and thickness of samples and decreasing in the moisture content of sample caused a darker dried-product. So using the low air temperature or thin slice is necessary to achieve best color and good appearance.

Keywords: Color Characteristic; Drying kinetic; Garlic; Mathematical modeling.

Abbreviations:

a, b, c, n, k, k_1, k_2	coefficients and constants in drying models
a^*	redness of the color
b^*	yellowness of the color
L^*	lightness of the color
C	color density
N	number of observations
MR	moisture ratio
$\overline{MR}$	mean moisture ratio
M	moisture content ($g_{water}.g_{dry\ solid}^{-1}$)
RMSE	root mean squares error
SSE	sum of squares error
R^2	coefficient of determination
min	minute
T	air temperature (°C)
L	slice thickness (mm)
t	time (min)
ΔE	total color difference
T_{abs}	absolute temperature (°K)
Subscripts	
o	Initial
I	dried garlic
exp	Experimental
Pre	Predicted
E	Equilibrium

Introduction

Garlic (*Allium sativum* L.) is an important Allium spice that is a strong source ofphenolic compounds, phosphorus, potassium, sulfur, zinc, selenium and vitamins A and C and lower levels of calcium, magnesium, sodium, iron, manganese and B complex vitamins elements (Brewester, 1997). Garlic has antiseptic properties and is used in a number of medicinal preparations. Various garlic powder pills and garlic oil pills are now commercially available (Sharma and Prasad, 2006). It has been cultivated for centuries all over the world especially cultivated widely in Iran. Most of garlic has been used as a fresh vegetable without any preprocessing operation. It is also used for seasoning of foods because of its typical pungent flavor. Garlic is a semi-perishable product. Due to lack of suitable storage and transportation facilities, about 30% of fresh crop is wasted in postharvest stages by respiration and microbial

Table 1. Mathematical models of thin-layer drying

Model	Mathematical equation	Reference
Newton	$MR = \exp(-kt)$	Yaldiz et al., 2001
Page	$MR = \exp(-kt^{n})$	Doymaz, 2004
Henderson and Pabis	$MR = a \times \exp(-kt)$	Doymaz, 2004
Logarithmic	$MR = a \times \exp(-kt) + c$	Togrul and pehlivan, 2004
Approximation of diffusion	$MR = a \times \exp(-kt) + (1-a) \times \exp(-kbt)$	Lahsasni et al., 2004
Midilli & Kucuk	$MR = a \times \exp(-kt^{n}) + bt$	Midili et al., 2002
Verma	$MR = a \times \exp(-kt) + (1-a) \times \exp(-gt)$	Togrul and pehlivan, 2004
Weibull	$MR = \exp\left(-\left(\frac{t}{b}\right)^{a}\right)$	Marabi et al., 2004
Seiiedlou & Aghbashlo.	$MR = \exp\left(-\frac{k_1 t}{1-k_{2t}}\right)$	Seiiedlou et al., 2010

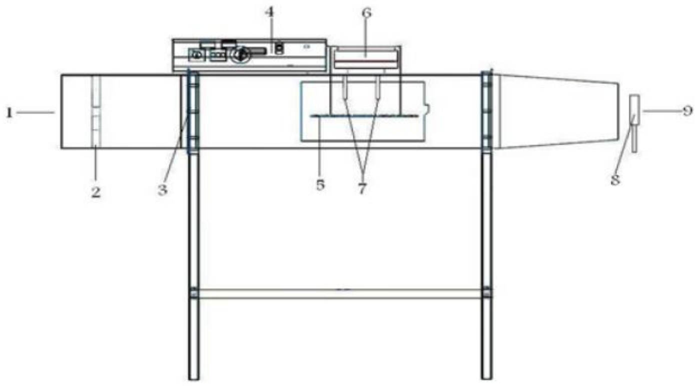

Fig 1. Schematic diagram of the convectional drying equipment (1) Air inlet; (2) Fan; (3) Heaters; (4) Temperature and air flow velocity controlling; (5) Perforated tray; (6) Digital balance; (7) Relative humidity sensor and thermocouple to data logger; (8) Digital anemometer; (9) Air outlet.

spoilage (Sharma et al., 2009). More recently, it has used in its dried form, as an ingredient of precooked foods and instant convenience foods including sauces, gravies and soups. These lead to a sharp increasing in the demand of dried garlic. To cater the demand of dried garlic and to overcome its storage problems, it should be processed quickly and optimally to maintain the quality. Drying is the most common food preservation method used in practice (Midilli et al., 2002) and dried garlic exists into different products such as powders, flakes and slices (Abbasi-Souraki and Mowla, 2008). The optimization of drying operation leads to an improvement in the quality of the output product, a reduction in the cost of processing as well as the optimization of the throughput (Madamba et al., 1994). In order to control and optimize the drying process and designing of the proper drying equipment, it is necessary to use the mathematical models describing the drying kinetic. Most of these models are empirical, although they are mainly derived from the diffusional model based on Fick's second law for different geometries (Akpinar et al., 2003). Thin layer mathematical models have been studied in drying of fruits, vegetables, seafood and other agriculture or crop products, such as mushroom and pollen (Midilli et al., 1999), grape (Yaldiz et al., 2001) eggplant (Ertekin and Yaldiz, 2004), apple (Sacilik and Elicin, 2006). The garlic reportedly has been dried using the microwave-vacuum technique (Figiel, 2009; Abbasi-Souraki and Mowla, 2008; Cui et al., 2003; Sharma and Prasad, 2001). Kim et al. (1992) determined the drying kinetics of garlic pretreated by immersion in 0.5% metabisulfite solution at the drying air temperatures 55 to 85°C. They found that this treatment considerably improved the quality of the dried product by preventing the browning reactions. Madamba et al. (1996) reported that the drying air temperature and the slice thickness were significant factors that affected the drying rates of thin garlic slices. Vazquez et al. (1999a) determined the drying kinetics of garlic slices at various slice thicknesses (1.5–5.0 mm), the drying air temperatures (40 to 60°C) and a constant drying air flow rate of 2.5 m.s^{-1}. In spite of published researches about the garlic drying kinetics that mentioned above, there is few published work on the mathematical modeling, quality characteristics changes and engineering properties such as effective moisture diffusivity and energy requirements. This research is part of a study on the processing of Iranian garlic genotypes. The aim of present study was the investigation of the thin layer convective drying behavior of garlic slices at different drying air temperatures and slice thicknesses to select the suitable mathematical model of drying kinetic and drying conditions. In addition, the effect of drying condition on the color changes was studied.

Table 2. Final drying time at different air temperatures and sample thicknesses

Drying air temperature (◦C)	Drying time (min)		
	Sample thickness (mm)		
	2	3	4
50	85	186	249
60	66	127	163
70	45	86	120

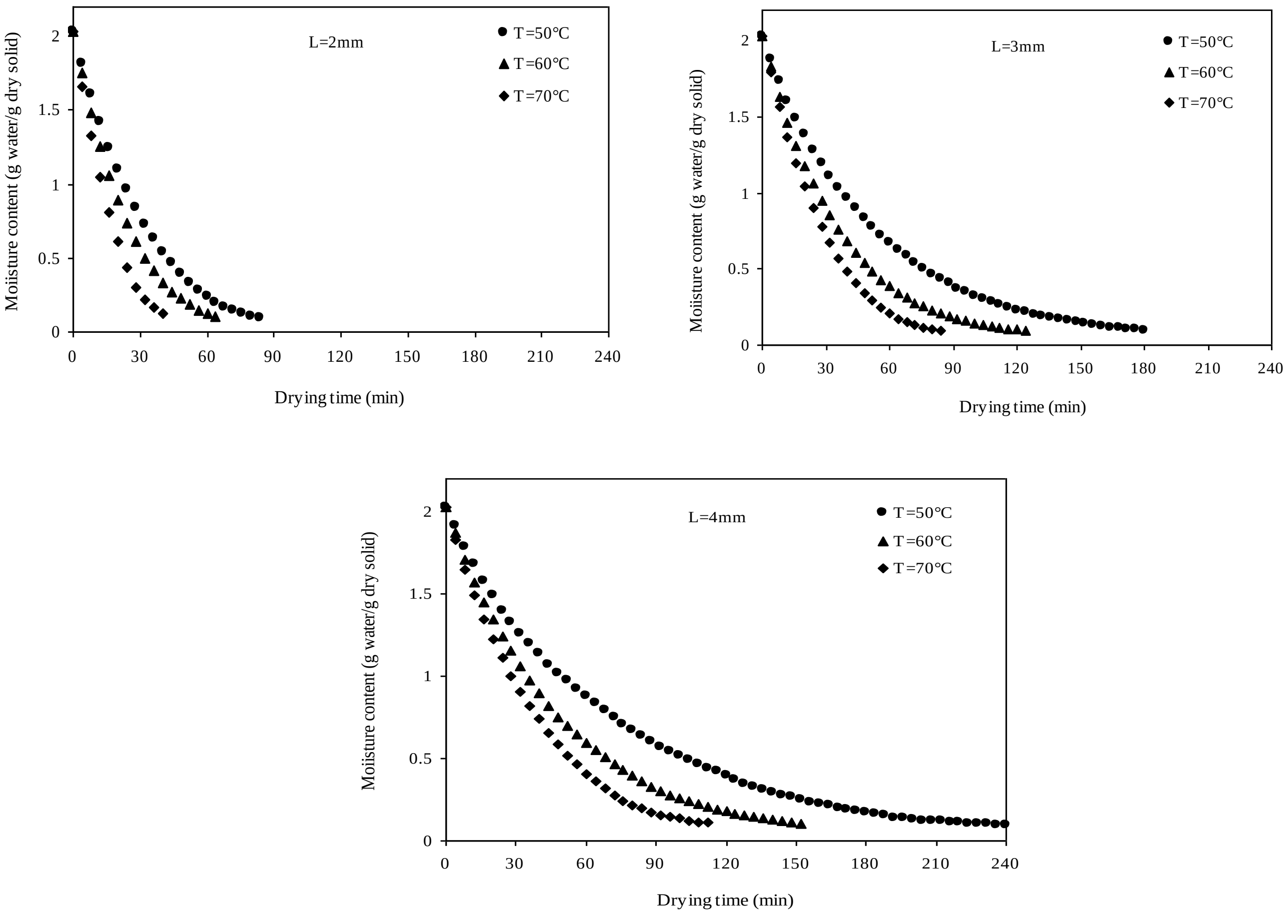

Fig 2. Drying curves of garlic at different air temperatures and sample thicknesses

Result and discussion

Drying curves

The analysis of variance indicated that the air temperature as well as the sample thicknesses had a significant effect on the drying time at the 1% probability level. The results showed that increasing the air temperature from 50 to 70 ºC led to decrease the drying time of garlic slices at all sample thicknesses (Table 2). The moisture content versus drying time at various air temperature and sample thickness are shown in Figs. 2. It is observed that increasing in the sample thickness increased the time required to reach to a certain level of moisture content. The drying time to reduce the moisture content of garlic slices from 2.03 to 0.09 ($g_{water}.g_{dry\ solid}^{-1}$) at sample thicknesses of 3 mm were 186, 127 and 86 min at 50, 60 and 70°C, respectively. These time values at other thicknesses, 2 and 4 mm, were 85, 66, 45 min and 249, 163 and 120 min, respectively. The lowest drying time was obtained at the air temperature of 70˚C and sample thickness of 2mm. Similar results were reported for garlic drying by several authors (Madamba et al., 1996; Vazquez et al., 1999a; Ratti et al., 2007). The variation of drying rate with moisture content is shown in Fig. 3. It is obvious from the curves that the drying rate decreases continuously with decreasing moisture content and the drying process occurred in the falling rate period only without a constant drying rate period. So the diffusion mechanism controlled moisture movement in the garlic slices. These results were in agreement with other studies on drying of garlic (Madamba et al., 1996; Ratti et al., 2007). The average drying rate values at 50, 60 and 70˚C and slice thickness of 3 mm were as 0.00022, 0.00031 and 0.00045 ($g_{water}.\ g_{dry\ solid}^{-1}.\ s^{-1}$), respectively. As expected, the drying rate increased with increasing in the drying air temperature and consequently decreased the required drying time. It is due to this fact that the higher temperature difference between the drying air and garlic slices increases the surface heat transfer coefficient, which influences the heat and mass transfer rate. Several authors reported similar results during drying of fruits and vegetables such as garlic, red chilies and apple (Sharma and Prasad, 2001; Madamba et al., 1996; Ratti et al., 2007; Sacilik and Elicin, 2006). The

Table 3. Result of statistical analysis on nine thin-layer drying models

Model	Thickness (mm)	Drying air temperature								
		50◦C			60◦C			70◦C		
		R²	RMSE	SSE	R²	RMSE	SSE	R²	RMSE	SSE
Newton	2	0.9954	0.0190	0.0134	0.9962	0.0173	0.0087	0.9898	0.0299	0.0173
	3	0.9995	0.0058	0.0026	0.9996	0.0051	0.0014	0.9967	0.0155	0.0093
	4	0.9984	0.0101	0.0102	0.9994	0.0060	0.0027	0.9980	0.0117	0.0070
Page	2	0.9996	0.0054	0.0011	0.9998	0.0044	0.0006	0.9991	0.0090	0.0016
	3	0.9999	0.0023	0.0004	0.9999	0.0031	0.0005	0.9997	0.0049	0.0009
	4	0.9995	0.0059	0.0035	0.9995	0.0056	0.0024	0.9991	0.0082	0.0034
Henderson & Pabis	2	0.9972	0.0149	0.0080	0.9977	0.0137	0.0052	0.9931	0.0253	0.0117
	3	0.9998	0.0040	0.0012	0.9997	0.0043	0.0009	0.9979	0.0123	0.0058
	4	0.9992	0.0072	0.0051	0.9995	0.0057	0.0025	0.9983	0.0110	0.0061
Logarithmic	2	0.9997	0.0046	0.0007	0.9996	0.0055	0.0009	0.9987	0.0110	0.0022
	3	0.9999	0.0029	0.0006	0.9999	0.0028	0.0004	0.9997	0.0048	0.0008
	4	0.9993	0.0068	0.0045	0.9997	0.0047	0.0015	0.9995	0.0061	0.0018
Midilli & kucuk	2	0.9999	0.0028	0.0003	0.9999	0.0030	0.0002	0.9995	0.0070	0.0009
	3	0.9999	0.0023	0.0004	0.9999	0.0025	0.0003	0.9998	0.0035	0.0004
	4	0.9997	0.0047	0.0016	0.9997	0.0041	0.0011	0.9996	0.0059	0.0017
Approximation of diffusion	2	0.9998	0.0040	0.0006	0.9999	0.0032	0.0003	0.9988	0.0111	0.0022
	3	1.0000	0.0022	0.0004	0.9999	0.0026	0.0003	0.9998	0.0046	0.0007
	4	0.9997	0.0046	0.0021	0.9995	0.0059	0.0025	0.9995	0.0059	0.0017
Verma *et al*.	2	0.9997	0.0048	0.0008	0.9998	0.0044	0.0006	0.9988	0.0111	0.0022
	3	1.0000	0.0022	0.0004	0.9998	0.0042	0.0009	0.9998	0.0046	0.0007
	4	0.9997	0.0046	0.0021	0.9995	0.0054	0.0022	0.9995	0.0059	0.0017
Weibull	2	0.9996	0.0054	0.0011	0.9998	0.0044	0.0006	0.9996	0.0058	0.0016
	3	0.9999	0.0023	0.0004	0.9999	0.0031	0.0005	0.9997	0.0049	0.0009
	4	0.9995	0.0059	0.0025	0.9995	0.0056	0.0024	0.9996	0.0059	0.0022
Seiiedlou & Aghbashlo	2	0.9999	0.0026	0.0002	0.9998	0.0036	0.0004	0.9995	0.0065	0.0008
	3	0.9999	0.0032	0.0008	0.9999	0.0030	0.0005	0.9999	0.0028	0.0003
	4	0.9991	0.0077	0.0058	0.9995	0.0054	0.0021	0.9995	0.0061	0.0018

R²: Coefficient of determination; RMSE: Root mean squares error; SSE: Sum of squares error

drying rate versus moisture content at slice thicknesses of 2, 3 and 4 mm and air temperature of 60˚C are shown in Fig. 4. It is clear that at high moisture content, the difference between drying rates at different slice thicknesses was high, but at low moisture content, this difference was negligible. When the slice thickness was increased from 2 to 4 mm, the average drying rate decreased about 2 times.

Modeling of drying curves

Nine thin layer drying models were evaluated according to the statistical criteria such as R^2, RMSE and SSE (Table 3). By comparing the average values of these criteria, it is obvious that the Midilli-Kucuk had the highest R^2 and the lowest RMSE and SSE values. The second best model was the Seiiedlou and Aghbashlo model and the Weibull model was in the third grade. To take into account of the effect of drying air temperature (T) and slice thicknesses (L) on the coefficients of selected models, the values of coefficients were regressed against air temperatures and slice thicknesses using multiple regressions (Using Excel software). The multiple combination of different parameters which gave the highest $\overline{R}^2$ value, were finally included in selected model. Accordingly, the Weibull model was selected as a suitable model to represent the thin layer drying behavior of garlic slices. The coefficients of this model in all experiments are shown in Table 4.

The coefficients of the accepted model and the final MR equation of thin layer drying of garlic slices were as follows:

$$a = 5.994251 \times L^{-0.164} \exp\left(\frac{-516.322}{T_{abs}}\right)$$

$$\overline{R}^2 = 0.8128 \quad (6)$$

$$b = 6.02554 \times 10^{-6} \times L^{1.065} \exp\left(\frac{3429.964}{T_{abs}}\right)$$

$$\overline{R}^2 = 0.9721 \quad (7)$$

$$MR = f(T, L, t) = \exp\left(-\left(\frac{t}{b}\right)^a\right) \quad (8)$$

Some other extra experiments were conducted at the air temperatures of 55 and 65 ˚C and slice thicknesses of 2.5 and 3.5 mm to validate the developed model. Fig. 5 shows the

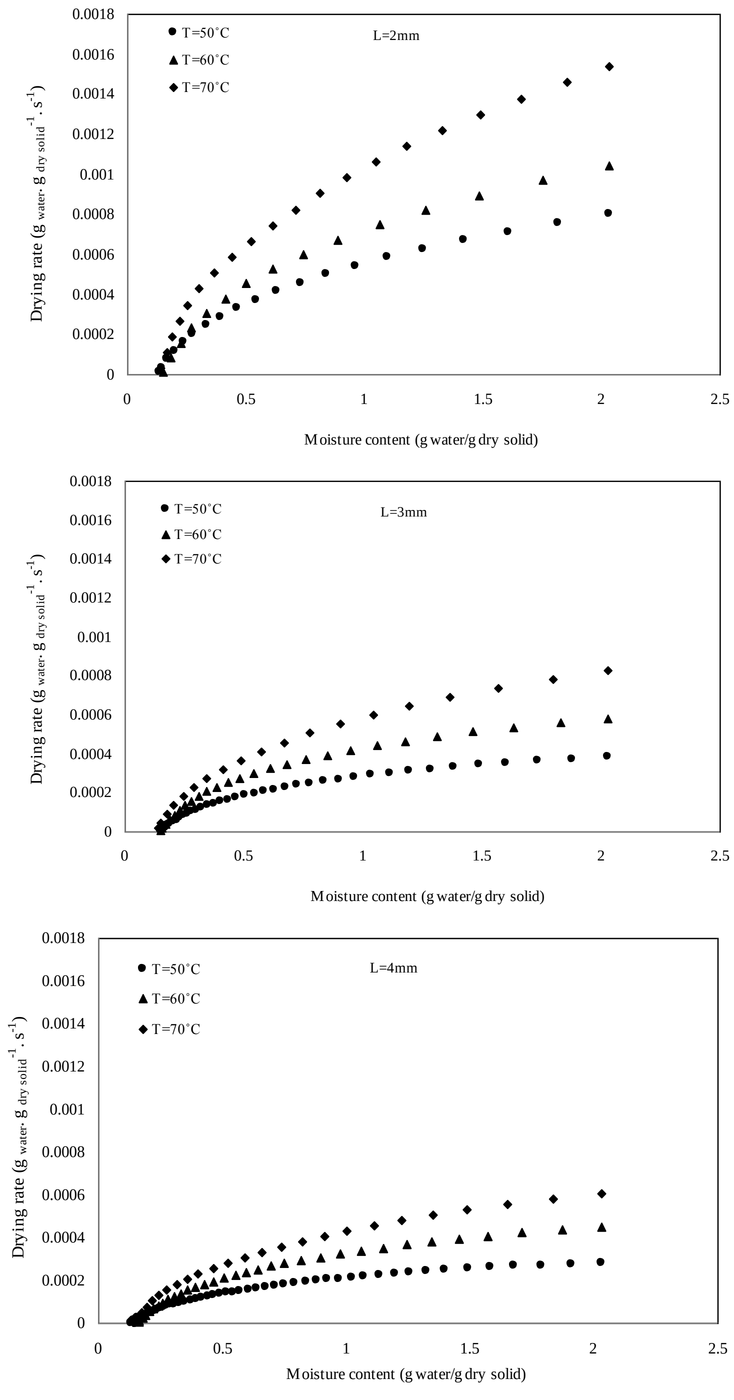

Fig 3. Drying rate vs. moisture content of garlic slices at different air temperatures and slice thicknesses.

comparison of the predicted and the experimental moisture ratio values at particular drying air temperature and slice thickness (55 ˚C and 2.5 mm). It is clear that the established model provided a good agreement between the experimental and the predicted moisture ratio values, which is bound around a 45˚ straight line.

Color changes

The air temperature and slice thickness had significant effect at 1% probability level on the final Hunter color values as well as C and ΔE of dried garlic slices (Table 5). The variation of color characteristics at different air temperature and slice thicknesses are shown in Fig 6 and 7, respectively. The results show that the L^* value decreases during the drying and other characteristics increases at all drying conditions. At all drying temperatures, the samples had the same L^* and a^* values until the moisture content of 1 $g_{water}.g_{dry\ solid}^{-1}$. Along with moisture content decreasing, the differences between these characteristics were growing. The sample at the 70 °C had the lowers and higher L^* and a^* values, respectively. At high drying temperature, the chemical reactions such as browning take place readily and cause the darker color (Fig. 6). Also at the high slice thickness, the samples had the lowers and higher L^* and a^* values, respectively. It was due to this fact that the drying time is longer at high slice thickness. So the samples experience such temperature for a long time and their color make darker consequently (Fig.7). For other characteristics, b^* and C, no trend was observed. Desired color properties of dried garlic slices are related to higher values of L^*, lower values of a^* and minimum total color differences (ΔE) of dried and fresh garlic (Cui et al., 2003; Figiel, 2009). In addition, L^* value of dried garlic slices at drying air temperature of 50°C and slice thickness of 2 mm (53.77) was higher than that of 70 °C and 4mm (45.73). In other word, higher drying air temperature and slice thickness led to darker garlic slices. Similar result was reported for color changes of garlic by Cui et al. (2003).

Materials and methods

Samples

Fresh garlic (*Allium sativum* L.) bulbs were obtained from a field located in Azarshahr (East Azarbaijan Province), Iran; and stored in a refrigerator at 4°C until experiments started. After 2h stabilization period at the ambient temperature, the bulbs by uniform size were selected and separated into cloves and peeled, then were cut them by a rotating disc slicer into slices of thickness (L) of 2, 3 and 4 mm. To prevent non-enzymatic browning, the garlic slices were dipped into a Sodium Metabisulfite ($Na_2O_5S_2$) solution of 4% w/w for 60s at 25°C temperature (Vazquez et al., 1999b). The initial moisture content of pre-treated garlic was determined by a mechanical convection oven at 102±1°C until constant weight was attained (AOAC, 1990). The initial moisture content of pre-treated garlic was 2.03 ($g_{water}.g_{dry\ solid}^{-1}$). The samples weight was measured by an electronic balance with a sensitivity of 0.001 g. Four replications were conducted to obtain a reasonable average.

Drying equipment

Drying experiments were performed in a pilot plant tray-dryer. A schematic view of the dryer is shown in Fig. 1. The dryer mainly consists of three basic units, a fan providing desired drying air velocity, electrical heaters controlling the temperature of drying air and drying chamber. The dryer was equipped with a data acquisition system and a controlling unit of temperature, air flow velocity and relative humidity. Air was flowed by an axial flow blower (90 W) and the velocity of air flow was controlled by changing the rotating speed of fan (SPC1-35, Autonics, Taiwan) and measured using a vane probe type anemometer (AM-4202, Lutron, Taiwan) with an accuracy of ± 0.1 m/s. Air was heated, while flowing through

Table 4. Coefficients of the Weibull model at different air temperatures and slice thicknesses

Thickness	2 (mm)		3 (mm)		4 (mm)	
Temperature	a	b	a	b	a	b
50◦C	1.115000	0.513033	0.968533	0.900033	0.952167	1.184333
60◦C	1.105667	0.393467	1.003000	0.610367	0.994067	0.812500
70◦C	1.185000	0.279500	0.922667	0.477700	1.051667	0.641200

Table 5. Summary of the analysis of variance for the effect of air temperature and slice thickness on color characters of dried garlic

Source of variation	Degree of freedom	Mean squares				
		L^*	a^*	b^*	C	ΔE
Temperature	2	43.952 **	30.575 **	53.529 **	23.495 **	94.385 **
Thickness	2	59.982 **	35.226 **	74.469 **	35.751 **	112.548 **
Temperature × Thickness	4	12.261 **	20.573 **	25.670 **	24.784 **	37.451 **
Error	18	6.880	23.428	3.458	7.592	3.653

** Significant at 1% probability level

three spiral type electrical heaters, having 5, 5 and 2 kW capacity. These electrical heaters turned off or on separately via a temperature control unit (TZ4ST-Autonics, Taiwan) depending on the changes in the temperature, to stabilize a constant air temperature during the each experiment with an accuracy of ±0.1 °C. Weighing system consisted of an electronic balance (AND GF3000, Japan) having an accuracy of ±0.01 g. During The drying process, the air temperature and relative humidity in the drying chamber were logged on a data acquisition system (Delta T, England) (Seiiedlou et al., 2010).

Experimental procedure

The dryer was adjusted to the selected temperature for about half an hour before the start of the experiments in order to achieve the steady state conditions. Then, the samples (about 120 g) were spread in a single layer on a tray that connected to the balance in the dryer. Weight loss of samples was measured and recorded every 120 s. Drying time was defined as the time required to reduce the moisture content of samples to 0.09 (g_{water}. $g_{dry\ solid}^{-1}$). Additional samples (180g) were put on a separate tray within drying chamber without connecting to the balance. These samples were used to observe and measure the color changes of garlic slices during and at the end of drying process when the moisture content of samples fell to 1.06, 0.43, 0.13 and 0.09 (g_{water}. $g_{dry\ solid}^{-1}$). Drying experiments were performed at the drying air temperatures of 50, 60 and 70°C, a constant air flow rate of 1.5 $m.s^{-1}$ using garlic slices with different thickness, 2, 3 and 4 mm. Each experiment was repeated three times.

Mathematical modeling of drying curves

The moisture content data obtained at different drying air temperatures and slice thicknesses during drying process were converted to the moisture ratio (MR). However, the MR was simplified to M/M_0 instead of the $(M - M_e)/(M_0 - M_e)$, because the values of the M_e are relatively small compared to M or M_0. Hence the error involved in the simplification is negligible (Ertekin and Yaldiz, 2004; Seiiedlou et al., 2010).
In this study some of the mathematical models were used to describe the drying kinetic of garlic slices (Table 1). Each MR equations were fitted to the experimental data. The models parameters were estimated by fitting the experimental data to the model equations by using the non-linear least square regression based on Levenberg-Morquardt algorithm. RMSE, R^2 and SSE were used as criteria for verifying the adequacy of fit (Sacilik and Elicin, 2006; Gorji-Chakespari et al., 2010; Seiiedlou et al., 2010).

$$SSE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2 \qquad (1)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \qquad (2)$$

$$R^2 = \frac{\left[\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR}_{exp}\right)\left(MR_{pre,i} - \overline{MR}_{pre}\right)\right]^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR}_{exp}\right)^2 \sum_{i=1}^{N}\left(MR_{pre,i} - \overline{MR}_{pre}\right)^2} \qquad (3)$$

Where $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental and predicted moisture ratio, respectively, N is the number of observations, $\overline{MR}_{exp}$ and $\overline{MR}_{pre}$ are the mean value of experimental moisture ratio and predicted moisture ratio, respectively. The model with the highest value of R^2 and the least values of RMSE and SSE was chosen as the best one for describing the thin layer drying characteristics of garlic slices (Ertekin and Yaldiz, 2004; Seiiedlou et al., 2010). The relationships between coefficients of the best model and the drying variables were determined using multiple regression analysis. All possible combinations of the different drying variables were tested and included in the regression analysis (Ertekin and Yaldiz, 2004; Sharma et al., 2005).

Color analysis

Surface color of fresh and dried garlic slices was measured using an apparatus that constructed in the Agriculture Machinery Engineering Department, University of Tabriz, Iran, according to the Yam and Papadakis (2004) recommendation. This uses a combination of digital camera (Sony Cybershot DSC-T90 12.1 Megapixels), computer, and graphics software (Adobe_Photoshop_CS4_Extended_ME) to measure and analysis the surface color of food products. Color measurements at each drying condition were made using three randomly selected slices at 10 different locations on each slices at different moisture content of samples and color coordinates (L^*, a^* and b^* values) determine. The $L^*a^*b^*$ model is an international standard for color measurement.

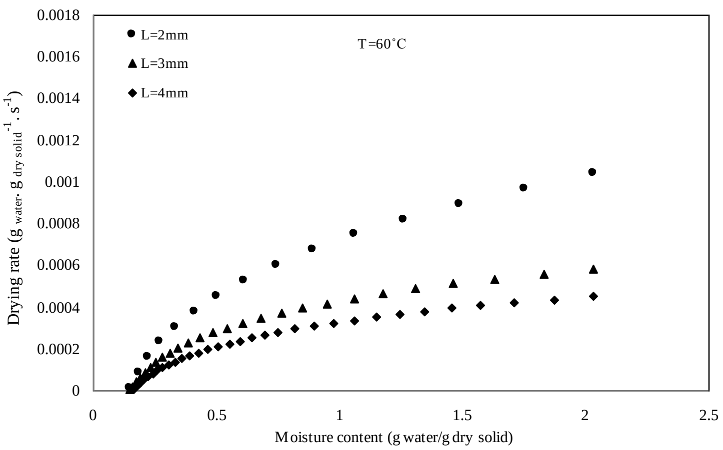

Fig 4. Drying rate vs. moisture content of garlic slices at air temperature of 60˚C and slice thicknesses of 2, 3 and 4 mm

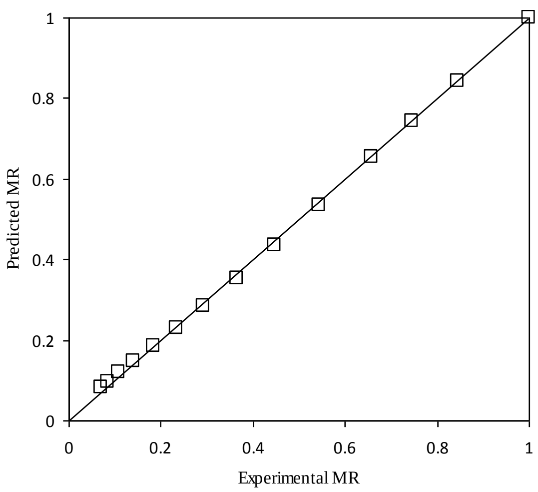

Fig 5. Predicted moisture ratio by Weibull model vs. experimental values at the air temperature of 55˚C and slice thickness of 2.5 mm

The $L^*a^*b^*$ model consists of a lightness component (L^*), along with two chromatic components from green to red (a^*) and from blue to yellow (b^*) (Yam and Papadakis, 2004). Color density (C) and the total color difference (ΔE) were then determined using the following equations (Demir et al., 2004):

$$C = \left(a^{*2} + b^{*2}\right)^{1/2} \quad (4)$$

$$\Delta E = \left[\left(L_0^* - L_I^*\right)^2 + \left(a_0^* - a_I^*\right)^2 + \left(b_0^* - b_I^*\right)^2\right]^{1/2} \quad (5)$$

where the subscripts 0 and I denote the color parameters of fresh and dried garlic slices, respectively.

Conclusions

The drying behavior of the garlic slices as a thin layer was investigated in a hot air dryer at air temperatures of 50, 60 and 70˚C and slice thicknesses of 2, 3 and 4 mm. The drying of garlic occurred in the falling rate period. This means that the diffusion mechanism controls moisture movement in the garlic. Drying air temperature and slice thickness affected the drying rate and time. The drying rate increased with increasing in drying air temperature and decreasing in slice thickness. In order to describing the drying behavior of garlic slices, among nine studied models, the Weibull model proposed, was found to be adequate for describing thin layer drying behavior of garlic slices, according to R^2, RMSE and SSE criteria. The final color characteristics values of dried garlic slices were affected significantly by air temperature and slice thickness at studied range of them. Increasing in the air temperature, sample thickness and decrease in the moisture content caused a decreased in lightness (L^*), and increased in yellowness (a^*) and redness (b^*) indicators.

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