Drying kinetic and shrinkage circumstance of Persian shallot bulb

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Abstract: The drying kinetics and volume shrinkage of Persian shallot bulb were looked at during air-drying. Six mathematical drying kinetics models were used, the non-linear page models represents good agreement with experimental data with average of Mean Relative Absolute Errors as 1.77%. Liner and exponential models were fitted to volume shrinkage containing with coefficients of determination from 0.956 to 0.998.

Keywords: drying model, shrinkage, Persian shallot

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1 Introduction

Persian shallot (*Allium hirtifolium*.) is one of the important edible alliums in Iran. It is different from common shallot (*Allium ascalonicum L.*) for many characteristics. The storage tissue of Persian shallot is bulb like (Figure 1), white skinned and usually consists of one main bulb or rarely a small bulblet attached to main bulb, the weight of each bulb being 8–15 times of garlic clove (Salunkhe and Kadam, 1998). Bulbs of Persian shallot are eaten in Iran where they are called "Mooseer". They grow wild across the cold mountains in different provinces of Iran, but common shallot is come from warm regions of west Asia (Salunkhe and Kadam, 1998). Most of Persian shallots are harvested from the wild, sliced, dried and sold. Persian shallot is a nutritive plant with special taste and its dried bulb slices are used as an additive to yogurt and pickling mixtures. Its powder is used as a tasty additive or spice for foods in Iran. Also, it has medicinal effects; aqueous extract of Persian shallot has shown antibacterial effects (Ashrafi et al., 2010) and suppresses the growth of Trichomonas vaginalis (Ebrahimi et al., 2009).

Figure 1 Wet Persian shallot bulb

Drying is a mass transfer process consisting of the removal of water by evaporation from a solid, semi-solid or liquid. This process is often used as a final production step before selling or packaging products. The final product must be solid, in the form of a continuous sheet (e.g., paper), long pieces (e.g., wood), particles (e.g., cereal grains or corn flakes) or powder (e.g., sand, salt, washing powder, milk powder). A source of heat and an agent to remove the vapor produced by the process are often involved. In bioproducts like food and grains, air heating increases the driving force for heat transfer and accelerates drying. It also reduces air relative humidity, further increasing the driving force for drying. In the falling rate period, as moisture content falls, the solids heat up and the higher temperatures speed

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up diffusion of water from the interior of the solid to the surface. However, product quality considerations limit the applicable rise to air temperature. Excessively hot air can almost completely dehydrate the solid surface, so that its pores shrink and almost close, leading to crust formation, which is usually undesirable.

Drying is one of the most important steps in Persian shallot production. Almost all fresh Persian shallot bulbs (with about 70% moisture content, wet basis) have to be dried to low moisture content (10%) in short time after harvest. The current drying method used in the Persian shallot industry is air-drying.

One of the significant criteria in designing of industrial dryers is the forecasting of moisture contents of matter while drying. These contents were decreased during dehydration procedure. Shrinkage during drying is important in determining the quality of the dried product. The purpose of this study was to investigate the suitability of the well-known mathematical models that were used to describe drying of biological materials and evaluation of shrinkage, in drying process of single Persian shallot bulb when fully exposed to air at different temperature and velocity. No similar work has been done on Persian shallot.

2 Materials and methods

Moist Persian shallots were used in this study. For each test, the best quality Persian shallots graded by experts were obtained from local market in Iran, Ilam province during March 2012. After cutting the roots and stem, the sample bulbs were washed and blot dry with tissue paper. The initial moisture contents of samples were determined by oven drying at temperature of 130°C for 6 h according to ASABE standard method (ASABE, 2006).

Single Persian shallot bulbs between 20 to 25 g weigh, 4 to 5 cm polar diameter and 3 to 4 cm equatorial diameter was hanging on a long piece of wire of load cell on special dryer then the variation of weight of bulb recorded and moisture content were determined for any time. The difference in weight was taken as water loss and expressed as kg water per kg initial weight. All experiments were repeated in three times.

2.1 Experimental procedures

The test apparatus is shown in Figure 2. The dryer is made up of a variable speed fan, an electric heater and ultrasonic humidity generator. Air velocity was kept at 1.0 and 2.00 m/s with an accuracy of ±0.1 m/s measured with an anemometer plus temperature and humidity meter (AM-4205A Lutron) with RS-232 USB computer interface flowed to air. During the tests, the relative humidity was kept at 45%±3% by using an ultrasonic humidifier (UCAN).

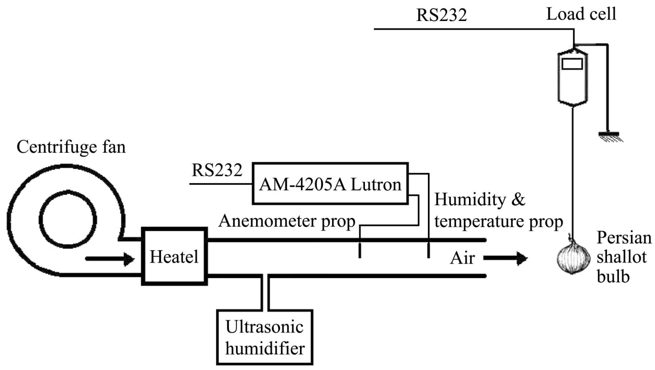

Figure 2 Schematic of the test apparatus

When the samples were drying, the digital force gauge (FG-5005 Lutron) with RS-232 USB computer interface and an accuracy 0.01 g measured weight of Persian shallot bulb for any time. For long term stability the drying temperature was controlled by fuzzy-supported controller at 34°C, 40°C, and 50°C with the sensitivity ±1°C.

Three digital image of each bulb sample was captured by a digital camera (E-510, Olympus, Tokyo, Japan) with macro lens (35MM, Zuiko, Tokyo, Japan), where the camera position was fixed in the 120 degrees angle of the horizontal field of vision during examination. The image size was 7256 × 5472 pixels, and the image resolution was about 240 pixels mm^{-1}. Changes in bulb surface were calculated from differences in pixel number (sum of three camera position) between images in each drying time using graphic software (Photoshop CS2, Adobe, San Jose, CA., U.S.A.).

2.3 Drying models

Drying curves were fitted with six moisture ratio models that were tried in several researches such as: thin-layer drying characteristics of garlic slices (Madamba et al., 1996), drying of eggplant and selection of a suitable thin layer drying model (Ertekin and Yaldiz, 2004), Dehydration characteristics of kastamonu garlic slices (Sacilik and Unal, 2005), modeling of hot-air drying of pretreated cassava chips (Tunde-Akintunde and Afon, 2010), modeling of vacuum-infrared drying of pistachios (Kouchakzadeh and Haghighi, 2011).

Newton (Westerman et al., 1973), Page (Page, 1949), Henderson Pabis (Henderson and Pabis, 1961), Logarithmic (Yaldiz et al., 2001), Wang and Singh (Wang and Singh, 1978) and Verma et al. (Verma et al., 1985) models are represented as Equation (1), Equation (2), Equation (3), Equation (4), Equation (5) and Equation (6), respectively. These models have been used to describe the drying of biological materials.

$$X=\exp(-kt) \tag{1}$$

$$X=\exp(-kt^n) \tag{2}$$

$$X=a\exp(-kt) \tag{3}$$

$$X=a\exp(-kt)+c \tag{4}$$

$$X=1+at+bt^2 \tag{5}$$

$$X=a\exp(-kt)+(1-a)\exp(-gt) \tag{6}$$

In all above equations $X=x/x_0$ shows the ratio of present moisture to its initial moisture in any time, t is time, and other factors are the empirical values that were calculated by curve fitting technique with using software (Table Curve V.1.12, Jandel Scientific, Germany). The acceptability of models was determined by the Mean Relative Absolute Error (MRAE) according to Equation (7), Equation (8) and Equation (9) as (Willmott and Matsuura, 2005):

$$e_i=\frac{(X_i-X_i^c)}{X_i^c} \tag{7}$$

$$E=\sum_{i=1}^{n}Abs(e_i) \tag{8}$$

$$MRAE(\%)=\frac{E}{n}\times 100 \tag{9}$$

where, e_i is the fractional error; E is the sum of absolute errors, and $MRAE$ is the Mean Relative Absolute Errors.

2.4 Shrinkage models

The shrinkage is expressed as the relative change of volume, area or thickness (or diameter if spherical). For volume reduction, it is expressed as Equation (10) (Chen and Mujumdar, 2009):

$$S=\frac{V}{V_0} \tag{10}$$

where, S is the shrinkage; V and V_0 are the present and initial volumes. The volumes may be substituted to number of pixels in three images in each drying time because of spherical similarity shape.

Many linear and non-linear mathematical models of volume change in correlation with moisture content of samples have been suggested. The liner models were used to describe carrot volume shrinkage (Hatamipour and Mowla, 2002) and exponential models were used for calibration of volume shrinkage in apple, carrot, potato and squid (Mayor and Sereno, 2004), which were presented respectively as Equation (11) and Equation (12):

$$S=A(x/x_0)+B \tag{11}$$

$$S=Ae^{B(x/x_0)} \tag{12}$$

3 Result and discussion

Table 1 shows the test results of Persian shallot bulb drying. The values of present moisture on initial moisture in any time (X) were shown in Figure 3. The experimented data (X) in 1 and 2 m/s air velocities were presented as a plot of differences of X vs. time (min) for each temperature as illustrated in Figure 4. Maximums differences of X were 0.07, 0.135, and 0.031 in 34, 40, and 50°C between air velocities. This shows a negligible difference, and cannot be justified using the higher air velocity. Drying kinetics of some vegetables such as potato, carrot, pepper, garlic, mushroom, onion, leek, pea, celery, pumpkin and tomato showed that the effect of air velocity is considered lower than that of air temperature (Krokida et al., 2003).

The calculated values for all six models were presented in Table 2. For comparison of best model selection the *MRAE* were calculated in Table 3. As shown in Table the Page models with lowest averages of *MRAE* 1.77% are the best fitted models and Henderson Pabis models with highest averages of *MRAE* 7.69% are the worst.

Table 1 The present moisture on initial moisture (*X*) of Persian shallot bulb

Air velocity		1.00 m/s			2.00 m/s		
Air temperature		34℃	40℃	50℃	34℃	40℃	50℃
Time /min	0	1	1	1	1	1	1
	30	0.936	0.977	0.954	0.944	0.971	0.926
	60	0.883	0.947	0.902	0.893	0.929	0.871
	90	0.841	0.911	0.830	0.861	0.884	0.813
	120	0.806	0.876	0.776	0.769	0.840	0.762
	150	0.773	0.841	0.724	0.731	0.790	0.718
	180	0.717	0.802	0.677	0.694	0.756	0.670
	210	0.692	0.764	0.621	0.667	0.709	0.632
	240	0.641	0.725	0.559	0.627	0.660	0.590
	270	0.616	0.690	0.522	0.595	0.599	0.511
	300	0.589	0.655	0.483	0.568	0.560	0.474
	330	0.566	0.584	0.408	0.534	0.518	0.426
	360	0.545	0.552	0.380	0.485	0.440	0.393
	390	0.518	0.517	0.342	0.467	0.406	0.354
	420	0.496	0.484	0.304	0.438	0.383	0.302
	450	0.475	0.452	0.273	0.418	0.342	0.269
	480	0.463	0.428	0.242	0.393	0.293	0.231

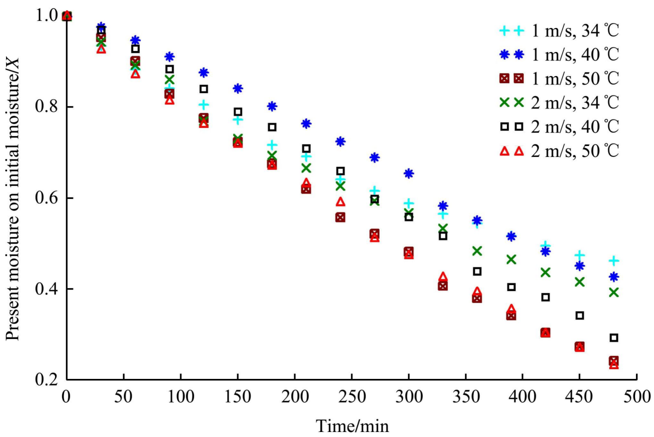

Figure 3 Variation of present on initial moisture of Persian shallot bulb (*X*) vs. time

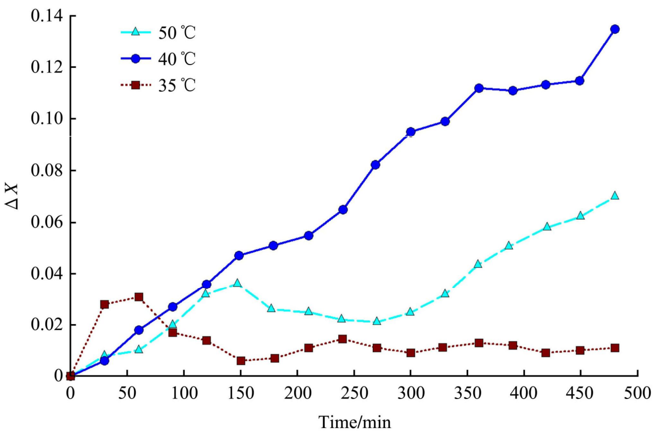

Figure 4 Variation of differences of *X* vs. time between 1 and 2 m/s air velocity

Table 2 The parameters of calculated drying models

Air velocity		1.00 m/s			2.00 m/s		
Air temperature		34℃	40℃	50℃	34℃	40℃	50℃
Newton	k	2.73e-3	1.94e-3	1.59e-3	2.48e-3	1.99e-3	1.58e-3
Page	k	0.56e-3	2.05e-3	3.40e-3	1.16e-3	0.19e-3	0.13e-3
	n	1.27	0.99	0.87	1.13	1.42	1.62
Henderson Pabis	a	0.96	0.97	0.98	0.97	0.95	1.12
	k	2.62e-3	1.94e-3	1.62e-3	2.42e-3	1.86e-3	4.23e-3
Logarithmic	a	1.71	0.97	0.77	2.22	10.74	3.26
	k	1.27e-3	2.05e-3	2.27e-3	0.87e-3	0.15e-3	0.84e-3
	c	-0.69	0.22	-1.23	-1.24	-9.72	-2.22
Wang and Sing	a	-2.00e-3	-1.87e-3	-1.72e-3	-2.03e-3	-1.23e-3	-2.43e-3
	b	8.64e-7	1.30e-6	1.33e-6	9.62e-7	-7.92e-7	4.42e-7
Werma, et al.	a	8.38	5.33	4.59	5.48	9.01	13.26
	k	4.77e-3	1.96-3	1.65e-3	4.04e-3	4.36e-3	8.20e-3
	g	5.23e-3	1.96e-3	1.63e-3	4.52e-3	4.82e-3	8.91e-3

Table 3 The Mean Relative Absolute Errors (MRAE)

Air velocity /m s^{-1}	Air temperature /℃	Model					
		Newton	Page	Henderson Pabis	Logarithmic	Wang and Sing	Werma, et al.
1.00	34	6.22	1.31	8.05	1.65	1.73	1.21
	40	1.06	1.07	2.45	1.09	1.19	1.07
	50	1.83	0.55	2.18	0.83	1.38	3.94
2.00	34	3.00	1.96	4.23	1.23	1.22	1.70
	40	5.33	1.67	7.41	1.58	0.90	1.69
	50	26.85	4.04	21.83	5.56	6.59	7.75
Average		7.38	1.77	7.69	1.99	2.17	2.89

The reduction in volume was observed during drying of the bulb. At various moisture contents, the changes in shrinkage coefficients were calculated and the results were shown in Figure 5. It was observed that the percentage shrinkage was higher in upper air temperature. This may be caused by the faster movement of moisture from the pulpy portion of the bulbs. The shrinkage coefficients of volume followed a liner and exponential trend as shown in Table 4. Related to coefficient of determination, in higher air velocity the exponential models have a better compatibility while in lower air velocity the liner model.

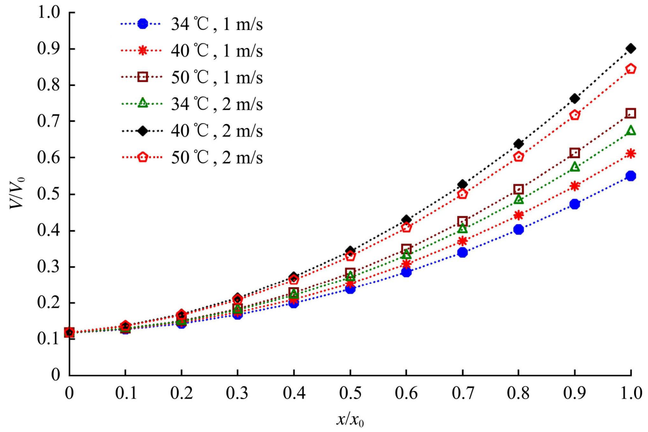

Figure 5 Variation of bulb shrinkage during drying

Table 4 The parameters of calculated shrinkage models

Air velocity		1.00 m/s			2.00 m/s		
Model	Air temperature	A	B	R^2	A	B	R^2
Liner	34°C	0.06106	0.4322	0.976	0.00973	0.603961	0.959
	40°C	0.05272	0.4933	0.970	-0.269367	0.848406	0.963
	50°C	0.3606	0.6044	0.993	-0.014171	0.727294	0.982
Exponential	34°C	0.104168	1.67537	0.969	0.108654	1.84023	0.998
	40°C	0.121712	2.7338	0.962	0.125821	1.99380	0.996
	50°C	0.138186	2.37491	0.956	0.123855	1.94449	0.996

Conclusions

The effects of air temperature and air velocity on the drying process of Persian shallot bulbs were investigated. The Page models were predicted the drying process and exponential and liner models for volume shrinkage. Temperature of air drying is the most significant factor of drying rate for all the examined materials, while the effect of air velocity is measured low.

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