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Thin layer drying of banana

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ABSTRACT

Drying is known as one of the oldest and best method for keeping the agricultural materials and food products. In process of drying, utilization of energy makes that drying seems an activity with the most consumption of energy. In this paper, kinetics of drying of banana pieces was carried out using Hybrid Dryer. In our experiments, dryer were regulated in velocities of air of 1, 1.5 and 2 m/s and temperatures of 60, 70 and 80℃. Banana pieces were cut with thickness of 5 millimeter. In order to achieve the fit model in molding of kinetics of drying, it must be examine the models. Thus, in this research, 8 models were selected randomly to obtain the fit model. In evaluation of models, among the 8 models, Aghbashlo model was fit model. The model called fit model that it has highest value for R^2 and lowest values for RMSE, χ^2 and MBE in all of the experiments. Variation domain of energy of activation and diffusivity of moisture of effective were 6.52×10^{-9} to 9.20×10^{-9} m^2/s & 50.61 to 53.79 kJ/ mol., respectively.

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Introduction

The phrase of drying means remove the moisture from solid material using evaporation in control circumstances [1]. In process of drying, there are many problems in drying of ancient methods. These problems include undesirable variation in quality of agriculture products, much dependent to the air circumstances, loss the vitamins and mineral materials of the food products, lack of sufficient control in process of drying kinetics, perform the process of drying in an extreme time, sully the product using dust, drying the product in an irregular time, require too much space for drying kinetics. Thus, these parameters need to new technology for process of drying [2]. Nowadays, industrial dryers have valuable position in process of drying of agricultural products. 400 dryers were devised hitherto that among these dryers, 50 dryers is regular for process of drying [32]. Drying process of food materials consists of transfer of mass and heat [23]. The aim of drying process is utilization of minimum energy to obtain maximum removal moisture. Thus, after the process of drying, it must be give the optimum quality of food products [4]. Researchers assayed on the modeling of food materials and agricultural products such as potato slices [6], tarragon [9], organic tomato [34], corn [35], rough rice [39], carrot [3], pear [21], eggplants [7], barberries fruit [1], and apricot [31] , [38]. People consum the banana a lot in the world. This fruit is produced in tropical countries. Because of sugars and starch, this fruit has high nourishment and energy. In adition, banana have many of source of vitamines, potassium and protein and mineral materials. Banana has the most post-harvest losses. Because, this product is rotten rapidly. Therefore, drying is the best method for keeping the fruit for a long time [20]. Many researches have been exist about kinetics of drying of banana pieces in the world [12], [25], [19], [17], [33], but no researches is not exist about kinetics of banana pieces with hybrid dryer in Iran. Thus, the principal aims of this paper include determination of fit model in examination of the 8 models using hybrid dryer, comput the energy of activation, calculate the diffusivity of moisture of effective, explain the influence of velocity of air and air temperature on the kinetics of drying of banana pieces.

Materials and methods

The variety of the banana fruit was Musa Sapientum that they obtained from kermanshah city (located in west of Iran) in summer 2015. This variety is consumed a lot in Iran, Thus, *Musa Sapientum* was selected for experiments. Dryer were regulated in velocities of air of 1, 1.5 and 2 m/s and temperatures of 60, 70 and 80℃. In experiments, Banana pieces were cut with thickness of 5 millimeter. With preparation of the product, 300 g banana pieces were converted to required thickness. Knife and digital caliper with accuracy of 0.01 millimeter were utilized for preparation of the pieces. For measuring moisture content, banana samples were weighed using digital balance with accuracy of 0.01g. Then, samples were transferred to the oven. Oven was regulated for standard temperature of 104℃ and for time of 24h [10]. Moisture content was obtained on basis of wet. The samples were weighed using digital balance before the process of drying kinetics. A temperature sensor (LM75) was located in the chamber dryer that was used for set the temperature of dryer. Anemometer device was utilized for measureing the air velocity.

In process of drying kinetics, the moisture ratio of banana pieces was computed using following equation [38]:

$$MR = \frac{M - M_e}{M_o - M_e}$$

(1) Where M is: moisture content at each time of drying process (kg water/kg dry matter), M_o is primary moisture content (kg water/kg dry matter) and M_e is balance moisture content (kg Where $MR_{pre,i}$ is ith ratio of moisture of predicted, $MR_{exp,i}$ is ith ratio of moisture of experimental, N is observations number and m is constants number. Among the examined models, a model is known as appropriate model that it has water/kg dry matter).

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Because of negligible value of M_e, this parameter was ignored [1]. Therefore, ratio of moisture was converted to following equation:

$$MR = \frac{M}{M_0} \quad (2)$$

8 model of drying kinetics were selected randomly to achieve the fit model. 4 criteria were utilized for examination the 8 models. These parameters include determination coefficient (R^2), chi-square (χ^2), error of square of root mean (RMSE), and mean bias error (MBE) [38]. The equations of these parameters are presented in following terms:

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

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre,i})^2}{N-M} \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right) \quad (6)$$

highest value for R^2 and lowest values for χ^2, MBE and RMSE [14]. SPSS 20 software and Microsoft Excel 2010 were utilized for statistical analyses. The selected models are given in Table 1.

Table1. Models of drying kinetics of agriculture products and food materials.

Model name	Equation	Reference
Lewis (Newton)	$MR = \exp(-kt)$	[18]
Page	$MR = \exp(-kt^n)$	[16]
Henderson and Pabis	$MR = a\exp(-kt)$	[15]
Logarithmic	$MR = a\exp(-kt) + c$	[39]
Tow-term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$	[35]
Wang and Singh	$MR = 1 + at + bt^2$	[40]
Midilli et al	$MR = a\exp(-kt^n) + bt$	[29]
Aghbashlo et al	$MR = \exp\left(\frac{-k_1 t}{1 + k_2 t}\right)$	[3]

Fick's second law is utilized for diffusivity of moisture of effective to model the behavior of agricultural materials in process of drying kinetics. Below Tentative equation is utilized for diffusivity of moisture of effective [7]:

$$MR = \frac{M}{M_0} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\exp\left(\frac{(2n-1)^2\pi^2 Dt}{4L^2}\right) \quad (7)$$

The following equations are given for indicating the relation between ratio of moisture, time of drying, diffusivity of moisture of effective and half thickness of fruit [27]:

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 Dt}{4L^2}\right) \quad (8)$$

Where n is 1, 2, 3, 4, 5 … Positive integer, t is drying time (s), D is diffusivity of moisture of effective (m^2/s) and L is half thickness of banana piece (m).

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 Dt}{4L^2} \quad (9)$$

A diagram of $\ln MR$ versus time of drying can be illustrated using Eq. 9. It means that this diagram gives a straight line with negative slant of K.

$$K = \frac{\pi^2 D}{4L^2} \quad (10)$$

Energy of activation is available using the equation of Arrhenius [6], [27]:

$$\ln D = \ln D_0 - \left(\frac{E_a}{RT_a}\right) \quad (11)$$

Where E_a is energy of activation (kJ/mol), R is constant of universal gas that this value equals 8.3143 kJ/mol K, T_a is air temperature of absolute (K) and D_0 is constant of equation (m^2/s).

Energy of activation was determined using diagram slant of Arrhenius equation ($\ln D$ against to $1/T_a$). A straight line was available by diagram of $\ln D$ against to $1/T_a$ in Eq. 11 that its slant was equaled to K_1.

$$K_1 = \frac{E_a}{R} \quad (12)$$

A criteria was used for evaluate the rate of drying versus time of drying that its equation is given in following term [5]:

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (13)$$

Where M_{t+dt} is: content of moisture at time of t + dt (kg water/kg dry mater), M_t is content of moisture at time of t (kg water/kg dry mater) and t is time of drying (h).

Results and discussion

An appropriate forecasting of the air temperature of the drying air along the drying process was available using kinetics of drying of food materials [26]. This research has indicated the influence of air velocity and air temperature on the kinetics of drying of banana pieces. For expressing the drying process, Diffusivity of moisture of effective versus moisture content was utilized [36].

Mean moisture content of banana pieces on wet basis was 70.87%. The data of moisture content were converted to moisture ratio, then they presented in form of drying kinetics at Table 1. The results of observed data of drying process of banana pieces are given in Tables 2, 3 and 4. It can be resulted from these tables that in all of the experiments, Aghbashlo model were selected as fit model in evaluation the 8 models. Because this model had high values for R^2 and low values for RMSE, χ^2 and MBE.

Constants of drying of fit model are reported in Tables 5, 6 and 6 for all of the air velocity. There is no aberration between predicted and observed moisture ratio in Figure 1 and this problem was an advantage for modeling of kinetics of drying of banana pieces. The diagram of Aghbashlo model is indicated in Figure 2 for observed moisture ratio versus predicted moisture ratio in air velocity of 1 m/s and temperature of 80°C for banana pieces. A new model was introduced by Aghbashlo et al., 2009, with topic about kinetics of drying of carrot pieces. Several researchers reported the parameters of R^2, χ^2 and RMSE [3]. The variation domain of their values was changed from 0.9996 to 0.9999, 2.032×10^{-8} to1.256×10^{-6} and 0.002491 to 0.004358, respectively. As seen in Figure 2, moisture ratio of banana pieces was decreased sequentially by increasing time of drying. Our results were agreed with the other researchers that they assayed on the kinetics of drying of banana pieces [12], [19], [17].

Table 2. Four criteria of examined for evaluation the models for air velocity level of 1 m/s.

Model	R^2	χ^2	RMSE	MBE
Newton	0.998	17.69×10^{-5}	12.54×10^{-3}	7.17×10^{-5}
Page	1	3.69×10^{-5}	5.35×10^{-3}	51.47×10^{-5}
Henderson and Pabis	0.998	18.51×10^{-5}	11.99×10^{-3}	18.2×10^{-5}
Logarithmic	1	0.238×10^{-5}	1.25×10^{-3}	74.56×10^{-5}
Tow-term exponential	0.998	85.17×10^{-5}	25.73×10^{-3}	39.95×10^{-3}
Wang and Singh	1	4.83×10^{-5}	6.13×10^{-3}	1.63×10^{-3}
Midilli et al	1	2.20×10^{-5}	3.49×10^{-3}	69.57×10^{-5}
Aghbashlo et al	1	3.27×10^{-7}	0.504×10^{-3}	16.82×10^{-5}

Table 3. Four criteria of examined for evaluation the models for air velocity level of 1.5 m/s.

Model	R^2	χ^2	RMSE	MBE
Newton	0.999	9.29×10^{-5}	9.09×10^{-3}	60×10^{-5}
Page	1	3.84×10^{-5}	5.46×10^{-3}	50.99×10^{-5}
Henderson and Pabis	0.999	10.59×10^{-5}	9.07×10^{-3}	71.18×10^{-5}
Logarithmic	1	0.711×10^{-5}	2.17×10^{-3}	72.14×10^{-5}
Tow-term exponential	0.999	39.80×10^{-5}	17.59×10^{-3}	31.51×10^{-3}
Wang and Singh	1	2.73×10^{-5}	4.61×10^{-3}	43.07×10^{-4}
Midilli et al	1	0.495×10^{-5}	1.65×10^{-3}	24.68×10^{-5}
Aghbashlo et al	1	7.72×10^{-11}	0.89×10^{-3}	0.258×10^{-5}

Table 4. Four criteria of examined for evaluation the models for air velocity level of 2 m/s.

Model	R^2	χ^2	RMSE	MBE
Newton	0.999	5.71×10^{-5}	7.12×10^{-3}	34.77×10^{-5}
Page	1	2.26×10^{-5}	4.19×10^{-3}	53.76×10^{-5}
Henderson and Pabis	0.999	7.05×10^{-5}	7.40×10^{-3}	35.61×10^{-5}
Logarithmic	1	7.28×10^{-5}	6.96×10^{-3}	66.50×10^{-5}
Tow-term exponential	0.999	10.91×10^{-5}	9.21×10^{-3}	5.89×10^{-3}
Wang and Singh	0.999	21.1×10^{-5}	12.82×10^{-3}	7.78×10^{-3}
Midilli et al	1	0.875×10^{-5}	2.20×10^{-3}	29.89×10^{-5}
Aghbashlo et al	1	3.66×10^{-7}	0.533×10^{-3}	0.177×10^{-5}

Table 5. Constants of drying for Aghbashlo et al model for air velocity level of 1 m/s.

Temperature(℃)	R^2	K_1	K_2
60	0.999	0.230	-0.020
70	0.999	0.201	-0.036
80	1	0.240	-0.039

Table 6. Constants of drying for Aghbashlo et al model for air velocity level of 1.5 m/s.

Temperature(℃)	R^2	K_1	K_2
60	0.999	0.270	-0.008
70	1	0.223	-0.042
80	1	0.287	-0.026

Table 7.Constants of drying for Aghbashlo et al model for air velocity level of 2 m/s.

Temperature(℃)	R^2	K_1	K_2
60	0.999	0.306	-0.001
70	1	0.263	-0.037
80	1	0.336	-0.014

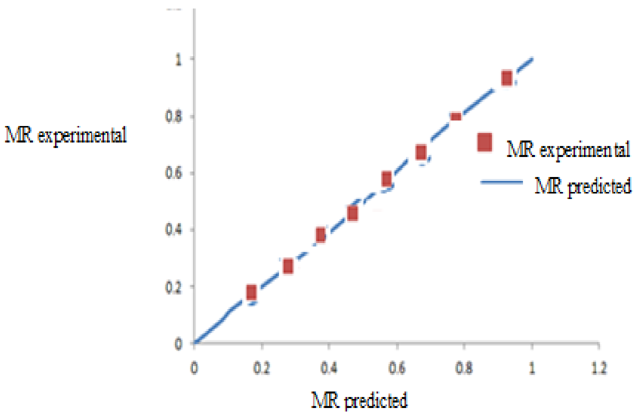

Fig 1. A sample of Aghbashlo el al model for MR experimental against MR predicted for banana pieces in air velocity level of 1m/s & temperature of 80℃ with R^2 = 1.

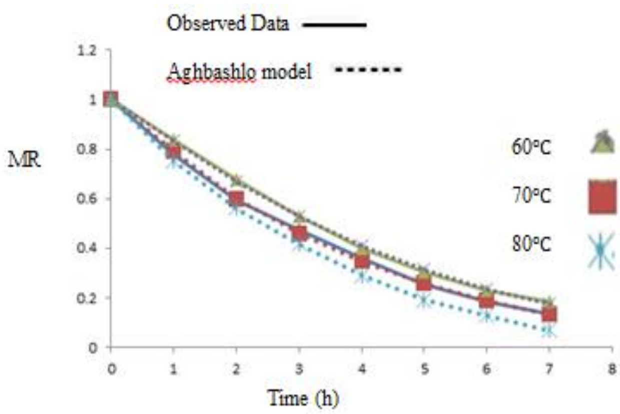

Fig 2. The diagram of Aghbashlo et al model (fit model) for observed and predicted moisture ratio against time of drying for air velocity level of 1 m/s with R^2 = 1.

The variation of rate of drying is illustrated as function of drying time in Figure 3. It is obvious that by increasing time of drying, rate of drying gradually increased, then with varying the drying time, any changes were not seen for drying rate that means drying rate was fixed by increasing time of drying. It is due to banana pieces were dried rapidly in higher air velocity, then the process of drying was reduced and after that no drying activity was occurred at end of the drying process. In this figure, it can be found out that air velocity had high influence on the rate of drying [22]. Our findings were related to other researchers that they performed many searches about kinetics of drying of banana pieces [33]. They understood that because of high value of moisture, rate of drying was high in start of drying process. The other researchers were in agreeing with our finding with topics of drying of pears [21] and drying process of carrot [3]. Generally, there are several parameters that affected on the kinetics of drying of agriculture products such as air velocity level and temperature of air [22]. With increasing the temperature of air, reduction of time of drying occurred [3].

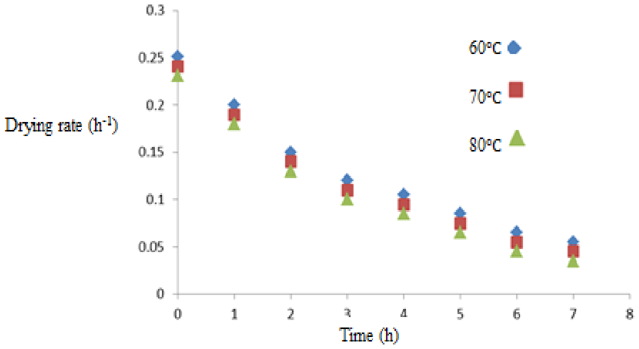

Fig 3. A sample of change of rate of drying against time of drying for banana pieces in different air velocities and temperature of 60℃.

The variation of Ln (MR) versus time of drying is illustrated in Figure 4 for air velocity of 1 m/s and for fit model (Aghbashlo model). Several researchers investigated correct of our results with drying of banana pieces and walnut, respectively [33], [22].

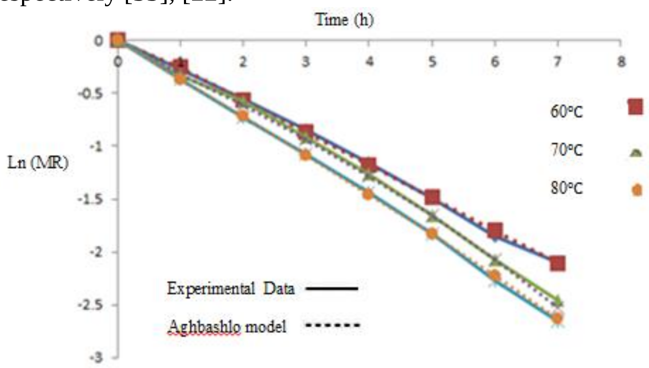

Fig 4. a sample of the Ln (MR) against time of drying for banana pieces in velocity of air of 1m/s and different temperatures.

Maximum and minimum of diffusivity of moisture of effective were 9.20×10-9 m2/s for velocity of air of 1 m/s and temperature of 80℃ and 6.52×10-9 m2/s for velocity of air of 2 m/s and temperature of 60℃, respectively. It can be observed that maximum of diffusivity of moisture of effective was obtained in minimum of air velocity level. This is due to air has a better contact with samples surface in air velocity level of 1 m/s (low velocity of air). It can be resulted that because of absorbing more moisture, sample moisture slant was increased with surroundings. Thereupon, diffusivity of moisture of effective was increased. While air passed from the samples surface in air velocity level of 2 m/s (high velocity of air). Therefore, slant moisture made that diffusivity of moisture of effective reduced [31]. It can be concluded from this research that diffusion coefficients was independent of moisture content (R2 = 1). By increasing the diffusion coefficient, temperature of air increased. Similar findings were confirmed our results [1]. In several researches, John et al., 2014 and Minh-Hue and William, 2007 reported the variation domain between 5.45 × 10-9 and 8.09 × 10-9 m2/s & 7.87 × 10-10 and 2.27 × 10-9 m2/s for blossoms of banana and banana pieces, respectively [25], [30]. In addition, another research was expressed values between 4.3 × 10-10 m2/s and 13.2 × 10-10 m2/s for various samples at temperature of 50℃ for pieces of banana [13].

Energy of activation is presented in various levels of velocity of air at Table 8. Variation domain of energy of activation was obtained between 50.61 and 53.79 kJ/ mol for different levels of air velocity of 1, 1.5 and 2 m/s. John et al., 2014 and Islam et al., 2012 found values of 50.06 kJ / mol and 51.21 kJ / mol for activation energy of blossoms of banana and green banana, respectively.

Table 8. Energy of activation for different levels of velocity of air of 1, 1.5 and 2 m/s.

levels of velocity of air (m/s)	Energy of activation (kJ / mol)
1	50.61
1.5	52.76
2	53.79

Conclusions

Drying experiments were carried out in various levels of velocity of air of 1, 1.5 and 2 m/s and different air temperatures of 60, 70 and 80°C. After the performing the experiments of drying kinetics of banana pieces, following results were achieved:

- In examination the 8 models of kinetics of drying, because of high value for R^2 and low values for RMSE, χ^2 and MBE, Aghbashlo model was fit model for all of various levels of velocity of air and different air temperatures.
- Temperature of air and velocity of air are included as important parameters in kinetics of drying of banana pieces.
- In comparison with the other air temperatures, when banana pieces was dried at air temperature of 60°C, appropriate quality of the product was obtained.
- Variation domain of diffusivity of moisture of effective and energy of activation were obtained between 6.52×10^{-9} and $9.20\times10^{-9} m^2/s$ & 50.61 to 53.79 kJ/ mol for all of different levels of velocity of air and various air temperatures, respectively.
- The experiments of drying of banana pieces occurred in step of rate of falling.
- Time of drying was utilized for forcasting as a function of conditions of air and variety characteristics.
- Longer time of drying occurred in lower temperature of air.
- In all of drying experiments, longer time of drying happened in lower temperature of air for all of different levels of velocity of air and various air temperatures.

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