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Drying Kinetics and Quality of Barberry in a Thin Layer Dryer

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ABSTRACT

The objective of this study was to investigate dehydration kinetics of barberry (*Berberis vulgaris* L.) at different drying temperatures (60 ºC, 70 ºC, 80 ºC), air velocities (0.3 m s^{-1}, 0.5 m s^{-1}, 1 m s^{-1}) with two types of pretreatment. Drying time and colour quality during dehydration were experimentally determined. Barberries were dried from the initial moisture content of 73.44% (w.b.) to the required moisture content of 18% (w.b.). Dehydration kinetics was monitored by measuring barberries weights at regular intervals. Convective drying curves were obtained for the treated and untreated barberries. The effect of two dipping pretreatments on drying kinetics of barberries was also studied. The two pretreatments were thermal shocking by immersing barberries in hot water, followed by cold water cooling, and dipping in olive oil and food grade K_2CO_3. Colour of the dried product was altered significantly during drying. The results indicated that the use of low temperatures is adequate for preserving this property. The air temperature significantly affected drying time and hunter colour indices of barberries ($P< 0.05$). With heat shocking and treatment with olive oil and K_2CO_3, drying time was reduced to about 40% and 60%, respectively. The total colour change (ΔE) and hue angle (H) increased with temperature. Moisture transfer from the test samples was described by applying the Fick's diffusion model for calculating the effective diffusivity. The effective moisture diffusivity (D_{eff}) of barberry increased as the drying air temperature increased. The D_{eff} values were higher for the treated samples than the untreated ones. These values were also higher for the samples treated with olive oil and $K_2 CO_3$ emulsion than those treated with hot water. The effective diffusivity of the untreated and the pre-treated varied between 2.57×10^{-13} and 9.67×10^{-12} m^2 s^{-1}, respectively. Higher colour change was observed in barberries treated with olive oil and K_2CO_3 emulsion. Statistical analysis showed that temperature and pretreatment had the most significant effect on drying time at $p<0.01$.

Keywords: Barberry, Colour change, Dehydration kinetics, Effective diffusivity, Pretreatment.

INTRODUCTION

Barberry fruit (*Berberis vulgaris* L.) is known as a medicinal and ornamental plant in the world (Aghbashlo *et al.,* 2008). Medicinal use of barberry dates back more than 2500 years and it has been used in Indian folk medicine to treat diarrhea, reduce fever, improve appetite, relieve upset stomach, and promote vigor as well as a sense of well-being. The ancient Egyptians used it with fennel seed to prevent plagues. During the early middle ages, European herbalists used it to treat liver and gallbladder ailments. Barberry fruit is known for its antiarrhythmic and sedative effects in Iranian traditional medicine (Aryan *et al.,* 2007). Today, it is widely used for medicinal purposes in Iran, including for biliary disorders (such as gallbladder disease) and heartburn. Iran is the largest producer of Barberry in the world. South Khorasan, a

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province of Iran, produces about 95% of barberry of the world. Each year, more than 4,500 tons are harvested in Khorasan region (Fathollahzadeh *et al.,* 2008). Berries are oblong, slightly curved, about half inch long and edible. The berries become red on ripening (Figure 1) and their taste is pleasantly acidic. The leaves are also acidic (Aryan *et al.,* 2007). Because of its acidic taste, fresh barberry is not consumed. Hence it is usually dried. Drying is the most widely employed method for preserving food materials; which is based on reduction of the water activity values through moisture removal to achieve physicochemical and microbiological stability (Moreira *et al.,* 2007). Dehydration of agricultural products in tray dryer involves more energy consumption mainly because the operation control and maintenance are carried out heuristically. For increasing the process efficiency and reducing the energy consumption, the process parameters have to be optimized. A convenient way to do this is to numerically simulate the total system behaviour and to predict the main parameter evolution for different operational conditions. Simulation codes for drying process are used to design, control, and improve new and existing drying systems.

The main obstacle for extensive analysis of the dehydration process by numerical simulation is the lack of thermo-physical properties for most of the agricultural products. On the other hand, the results from numerical simulation have to be validated by means of experimental investigation. The main problem in barberry dehydration is the slow rate of moisture removal during the drying process. This is because the rate of moisture diffusion through the berries is controlled by the waxy cuticle (Pangavhane *et al.,* 1998). In order to accelerate drying, mechanical and chemical methods have been applied to remove or modify the cuticle and increase barberry skin permeability to water. Thermal shocking of berries was carried out by immersing them in hot water for 1 minute and, immediately, dipping in cold water for the same time. The emulsion was made up of an approximately 6% food grade potassium carbonate (K_2CO_3) and 3% olive oil (Nicoletti Telis *et al.,* 2006). Effect of various pretreatments on drying rate and colour changes of the dried product have been conducted by many researchers on various vegetables and fruits such as apple discs (Acevedo *et al.,* 2007), Chempedak (Hwa Chong *et al.,* 2008), shrimp (Niamnuy *et al.,* 2008), Local Okro (Kuitche *et al.,* 2007), sour cherry (Doymaz, 2007), chestnuts (Moreira *et al.,* 2007). Browning in dehydrated fruits could be caused by enzyme action, taking place in early stages of processing, prior to polyphenoloxidase inactivation, or non-enzymatic browning (NEB), during drying. The qualification of brown discolouration is usually carried out by hand-held colourimeters (Acevedo *et al.,* 2007).

When deciding which process conditions produce the best quality dried products, it is necessary to compare drying time and quality parameters. The objectives of the present study were to determine experimentally the thin-layer drying characteristics of barberry under different drying conditions and to determine the effect

Figure 1. Barberry fruit (*Berberis vulgaris*).

of the different parameters (temperature, air velocity and pretreatments) on drying time as well as colour changes of dried barberry.

MATERIALS AND METHODS

The moisture content of the fresh berries was determined by drying in an oven at 105ºC for four hours until the mass did not change between the two weighing intervals, performed in triplicate (Aghbashlo *et al.,* 2008). Chemicals used for dipping sample were of technical grade.

Dipping and Shocking

To expedite drying by breaking the waxy layer of barberry skin, thermal shocking of the berries was carried out by immersing them in hot water, followed by cooling with cold water. To increase the water permeability of the skin, the berries were also dipped into a suspension of commercial olive oil and K_2CO_3. The solution of the desired concentration of K_2CO_3 was prepared in distilled water and heated at 50°C, on a hot plate with magnetic stirring. Olive oil was then added to this solution, which was kept under continuous agitation during dipping of the berries. The tested berries were treated as follows:

- E1: Dipped in hot-water at 85ºC for 60 seconds followed by immediate rinsing with cold water at 10 ºC.
- E2: Dipped in emulsion of 3% olive oil and 6% K_2CO_3 at 50ºC for 2 minutes.
- NAT: No pretreatment.

Experimental Procedure

Drying experiments were performed using a laboratory scale cross-flow hot-air dryer available at the Agricultural Engineering Department of Tarbiat Modares University, Tehran, Iran. The dryer consisted of a tray, an air flow system, an air drying heating section and the main drying chamber (Figure 2). The dryer was equipped with an automatic temperature controller (±0.1ºC), an online weight data recorder by using precision balance (0.01 g, A and D Model- Japan), load cell and an online data logger by using a computer program that recorded the weight loss of berries at 2-minute intervals. Experiments were carried out at hot air temperatures of 60, 70 and 80ºC. At each drying temperature, three velocity values were tested: 0.3, 0.5 and 1.0 m s^{-1}. For quantitative evaluation of the pretreatment effect, an experiment with untreated barberries was also included. To achieve a steady-state thermal condition, the dryer was set to work for about half an hour prior to the experiments. In each

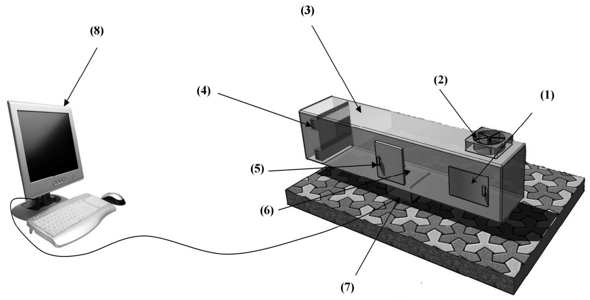

Figure 2. Schematic representation of the cross-flow hot air dryer: (1) Air velocity control, (2) Centrifugal fan, (3) Air heating chamber, (4) Heaters, (5) Door, (6) Place of tray, (7) Electrical balance with load cell, (8) Personal computer.

drying experiment, about 10 g barberries were placed on the tray of the drying chamber in a thin-layer formation. To ensure storage stability, the barberries were dried to the final moisture content below 18% (w/w). The experiments were repeated three times and the average of the moisture ratio at each time point was used for drawing the drying curves. The moisture ratio (MR) was calculated using the following equation:

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

where M_o, M and M_e are the moisture contents at initial stage, the time (t), and at equilibrium, respectively.

Calculation of Effective Diffusivity

In a drying process, diffusion is the mechanism for the transport of moisture from the inside of an object to its surface, which is then followed by the mass transfer of the moisture via evaporation to the environment surrounding the object. The mechanisms of mass transfer in foods are complex. Frequently, the modeling of the drying curves during the falling rate period is carried out by assuming that the main mechanism is of diffusional nature. Therefore, the diffusion coefficient estimated from experimental results is an effective parameter that includes the effects of the known hypotheses together with the unknown phenomena (Simal *et al.,* 2005). There are many methods used to calculate drying diffusion, the most common being the solution of Fick's second law for a sphere, assuming that the moisture transport is primarily by diffusion with no external mass transfer limitation, shrinkage is negligible, and the diffusivity does not change with time and space (Crank, 1975).

The experimental drying data for the determination of diffusivity coefficients were interpreted by using Flick's second diffusion model:

$$\frac{dM}{dt} = D\frac{d^2M}{dr^2} \qquad (2$$

To solve Equation (2), the initial moisture concentration is assumed to be uniform and external gas phase mass transfer resistance is negligible, that is, moisture movement is controlled by internal resistance and the outer surface concentration is not varying in time. General series solution of Fick's second law in spherical coordinates is given as follows (Crank, 1975):

$$\frac{M - M_e}{M_0 - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp(-\frac{n^2\pi^2 D_{eff}}{r^2}) \qquad (3$$

where D_{eff} is the effective diffusivity ($m^2\ s^{-1}$) and r is the radius of the sphere (m). For long drying times, Equation (3) can be simplified to a straight-line equation in the following form:

$$\ln(\frac{M - M_e}{M_0 - M_e}) = \ln(\frac{6}{\pi^2}) - (\frac{\pi^2 D_{eff} t}{r^2}) \qquad (4$$

The effective diffusivity values were calculated by Equation (4), using the method of slopes. It is typically determined by plotting experimental drying data in terms of *ln*(MR) versus time. From Equation (4), a plot of *ln*(MR) versus time gives a straight line with a slope of:

$$Slope = \frac{\pi^2 D_{eff}}{r^2} \qquad (5$$

Volume (v) of a single berry was determined using toluene displacement method of 100 berries. The equivalent radius of the barberry berry was found out by equalizing the volume of a single berry with the equal volume of sphere with radius r_e as 3.57×10^{-4} m (Mohsenin, 1986).

$$v = \frac{4}{3}\pi r_e^{\,3} \qquad (6$$

Colour Measurements

The appearance of both fresh and dehydrated barberries was assessed by a colour-difference meter technique using ColourFlex spectrophotometer (Novasys Group Pty Ltd) based on Hunter L^*, a^*, b^* colour scale.

Fresh barberries were used as reference material. The colour difference (ΔE) and hue angle (H) were determined using Equations (7) and (8).

$$\Delta E=\sqrt{(L_0^*-L_f)^2+(a_0^*-a_f)^2+(b_0^*-b_f)^2} \quad (7$$

$$H=\tan^{-1}(\frac{b^*}{a^*}) \quad (8$$

Where ΔE is the colour difference, H is the hue angle in degree, L_0^*, a_0^* and b_0^* are, respectively, the colour lightness, green-red and blue-yellow chromaticity of the fresh barberries, and L_f, a_f, and b_f are the colour lightness, green-red and blue-yellow chromaticity of the dehydrated barberries, respectively. The colour was measured for three samples of the treated and untreated samples and the average values were quoted.

Statistical Analysis

Two full-factorial experimental designs were used in this study. The effects of the drying air temperature, air velocity, and the type of pretreatment on colour values were determined by univariate full-factorial analysis of variance (ANOVA) using SPSS software (version 16). Data were presented as mean values and were compared with each other using Duncan's multiple range tests at a confidence level of 95%.

RESULTS AND DISSCUSION

Drying Characteristics of Barberry

The moisture content of the fresh berries was about 73.44% (w.b.). Drying curves, showing moisture ratio versus time, were drawn for the pretreated and untreated barberries dried at the constant inlet air temperatures of 60, 70 and 80ºC and air velocities of 0.3, 0.5 and 1 m s^{-1}. The curves of the untreated barberries are shown in Figure 3. Treated samples also followed this trend and the results are shown in Figure 4. In the case of heat shocking and the treatment with olive oil and K_2CO_3, drying time was reduced to about 40% and 60%, respectively (Table1). Temperature is a significant factor in drying process. As expected, drying time decreased with

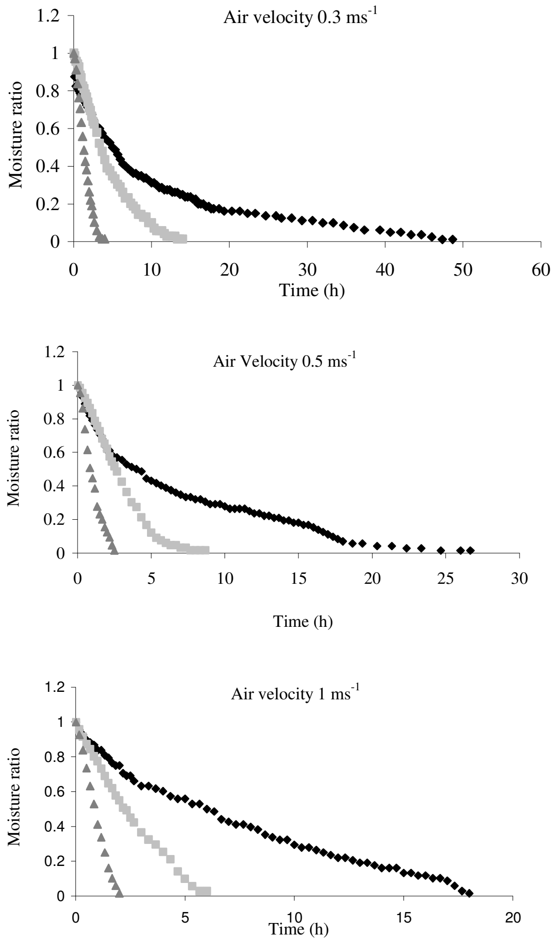

Figure 3. Influence of air temperature on the moisture ratio of untreated barberries, at different air velocity(◆60ºC, ■70ºC, ▲80ºC).

Table 1. Drying time of experiments (Minute).

Code	Air temperature(ºC)	v=0.3 m s^{-1}	v=0.5 m s^{-1}	v=1 m s^{-1}
	60	2920	1260	1080
NAT	70	840	520	360
	80	200	160	120
E_1	60	1920	1040	620
	70	320	240	160
	80	130	110	90
E_2	60	1080	940	400
	70	220	180	140
	80	120	90	70

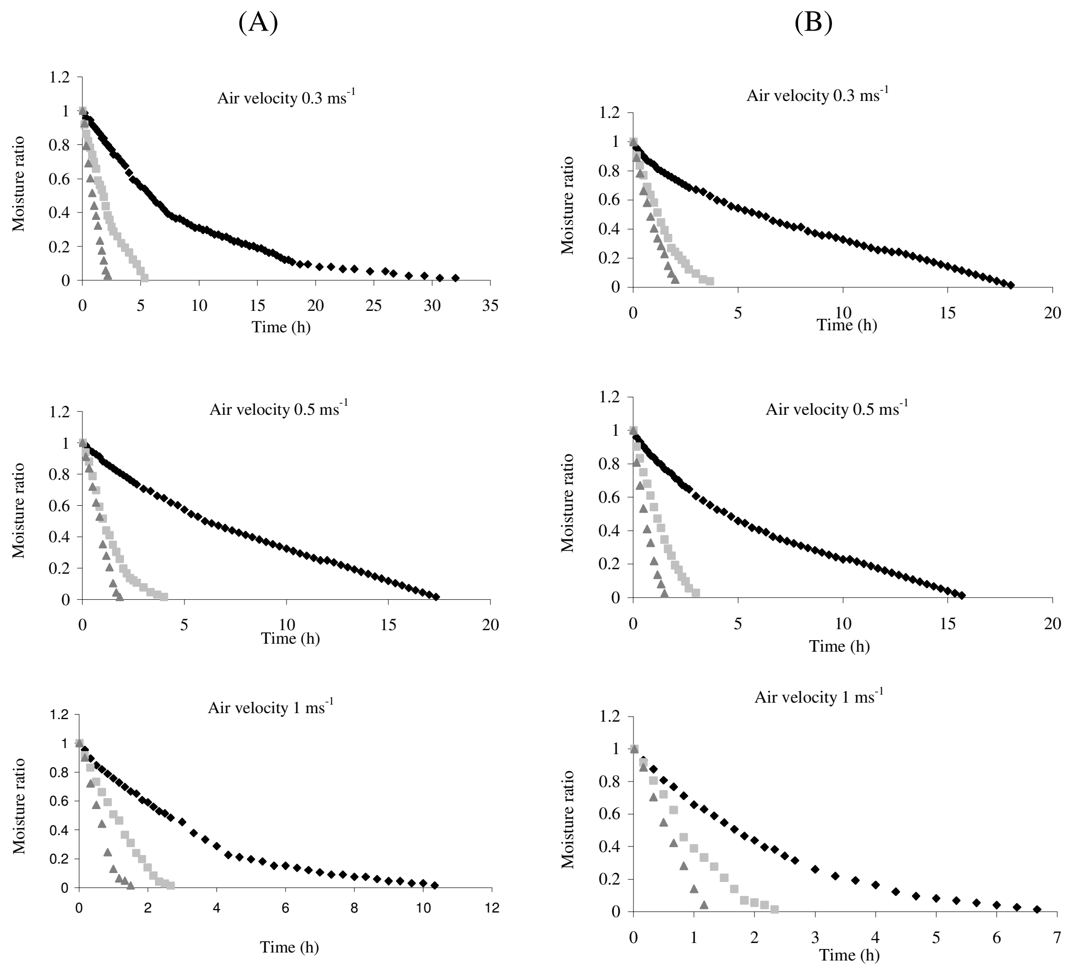

Figure 4. Influence of air temperature on the moisture ratio of treated barberries with Heat shocking (A) and olive oil+6%K2CO3 emulsion (B), at different air velocity (◆60ºC, ■70ºC, ▲80ºC).

increasing drying temperature. Similar results were reported by Aghbashlo *et al.,* (2008) in the case of berberis fruit. Furthermore, drying time decreased with increasing air velocity. Similar results were obtained by different authors for drying of vegetables and fruits (Kuitche *et al.,* 2007, Doymaz, 2007, Xanthopoulos *et al.,* 2006). Besides, pretreatment is also an important parameter that affects the drying time. The fruit heat shocked and pretreated with olive oil and K_2CO_3 suspension showed a faster drying rate. As shown, the constant rate phase is not seen for this pretreatment. The resulting curves showed that the applied pretreatments were effective in accelerating the drying process, with lower moisture content at the same drying time being attained by barberries treated with a 3% olive oil and 6% K_2CO_3 emulsion (Figure 4B). The reason for the shorter drying time of treatment E2, as compared with E1, is that the emulsion not only removes the waxy layer surrounding the skin but also diffuses into the fruit, thus improving external and internal water transport. This behavior also might be attributed to the deposition of olive oil on barberry surface, which could be visually detected by the oily aspect of the dried barberries resulting from this treatment (Nicoletti Telis *et al.,* 2006). However, it can be noted that this pretreatment is more effective in decreasing the drying time. Statistical analysis of the results indicated that only the pretreatments and temperature had significant effects at 1% level of significance, while the effect of air velocity was insignificant. Furthermore, the interactive effect of these factors was also insignificant. The results of these analyses are shown in Table 2. Other studies on the influence of pretreatments with heat shocking and olive oil with K_2CO_3 on drying kinetics of grapes have shown similar results (Doymaz and Pala, 2002).

Determination of the Effective Diffusivity Coefficients

Figures 5-6 show the *ln*(MR) versus time (h) in constant value of velocity and different levels of temperatures. It is apparent that the moisture ratio decreases continuously with drying time in a non-linear trend. This indicates that the moisture movement is controlled by diffusion and that diffusion is dependent on the moisture content of the samples (Prachayawarakorn *et al.,* 2008). All the figures show that the drying of barberry fruits occurred in falling rate period. In other words, the liquid diffusion is by the dry wing force controlling the drying process and, therefore, the curves are straight lines. Plotted curves show that the increase in temperature increases the slope of the straight line. In other words, the effective moisture diffusivity increases, as

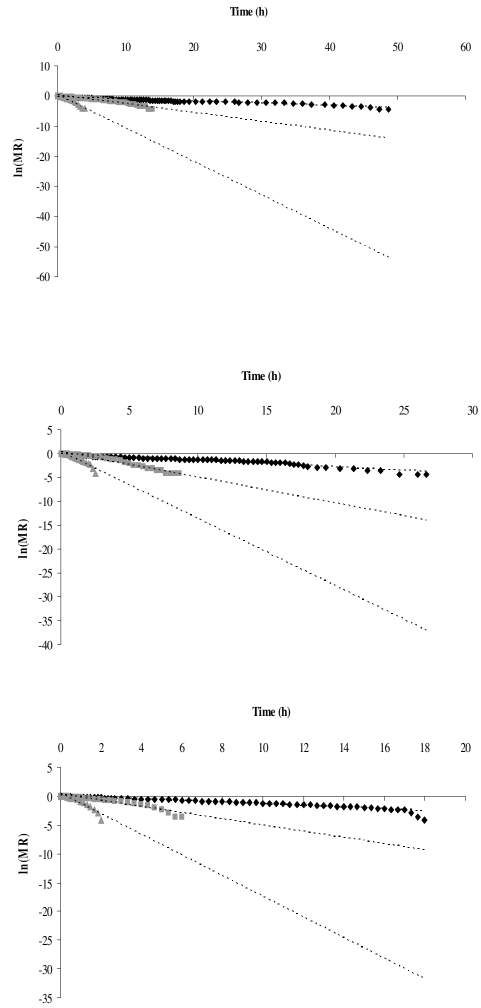

Figure 5. *Ln*(MR) versus time (h) for untreated barberries, at different air velocity (◆60ºC, ■70ºC, ▲80ºC).

Table 2. Effect of temperature, pretreatment and air velocity on drying time.

Source	Degree of freedom (d_f)	*MSE*[a]	*F*[b]
Pretreatment (NAT, E1, E2)	2	34.628	212.666[**]
Temperature, T	2	4.319	26.528[**]
Velocity, V	2	0.002	0.013[n.s]
(NAT, E1, E2) × T	4	0.230	1.412[n.s]
(NAT, E1, E2) × V	4	0.003	0.019[n.s]
V × T	4	0.000	0.003[n.s]
(NAT, E1, E2) × T × V	8	0.001	0.003[n.s]
Error	54	0.163	
Total	81		

[a] Mean square error, [b] Statistical distribution, [**] Significant at $P< 0.01$, ns: Not significant.

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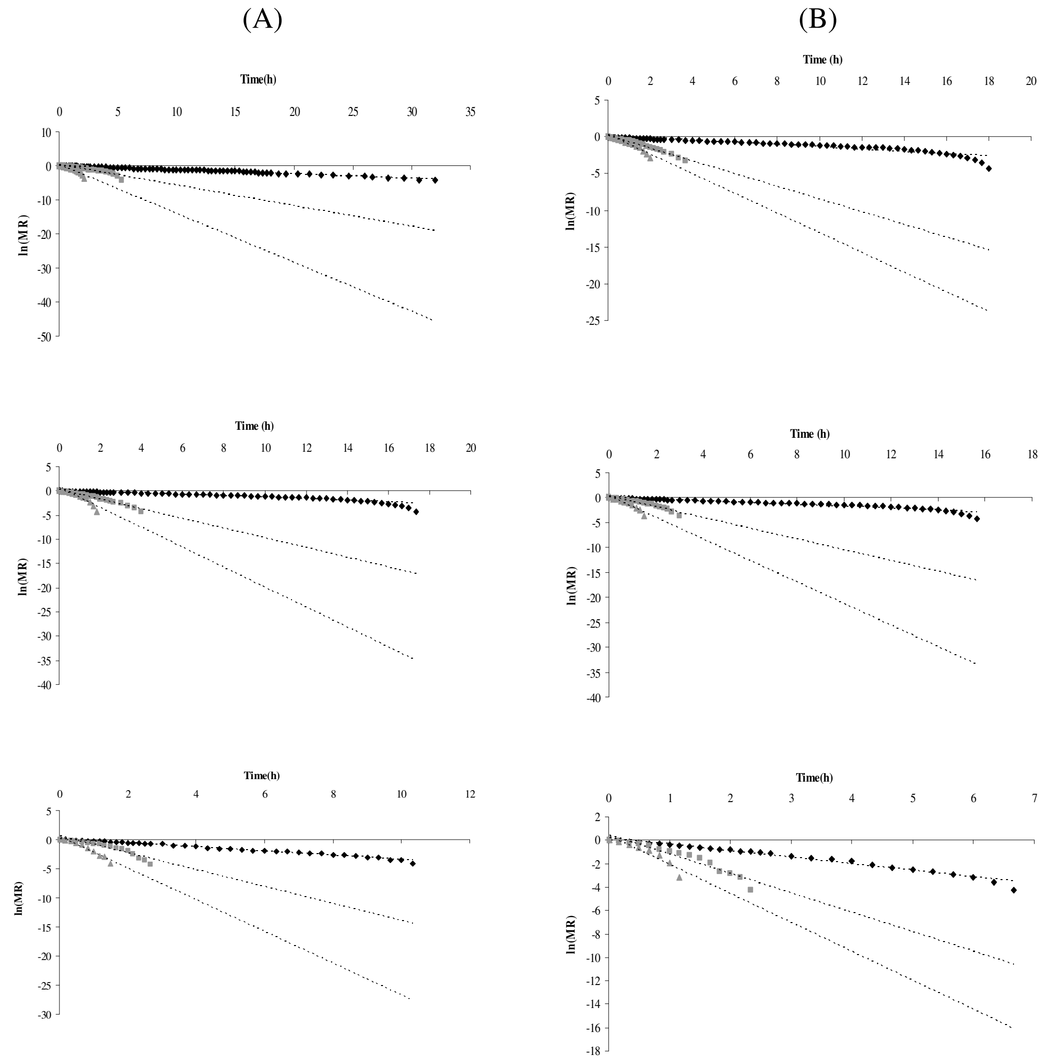

Figure 6. *Ln*(MR) versus time (h) for treated barberries with Heat shoching (A) and 3% olive oil+6%K2CO3 (B), at different air velocity (⬥60ºC, ▪70ºC, ▴80ºC).

well as the effect of air velocity, but, the effect of temperature is more obvious. D_{eff} was calculated using Equation (4). The maximum value of moisture diffusivity was obtained for the barberries treated with olive oil and K_2CO_3 emulsion and was equal to 9.67×10^{-12} m^2 s^{-1} when the air velocity was 1 m s^{-1} at air temperature of 80ºC. The minimum value of moisture diffusivity was 2.57×10^{-13} m^2 s^{-1} for the untreated barberries when the air velocity and temperature were, respectively, 0.3 m s^{-1} and 60ºC (Figure 7). The values of effective diffusivity of the pre-treated and untreated samples for each level of air velocity and temperature are reported in Table 3. All the figures show that the minimum value of D_{eff} belongs to the minimum air temperature. Other results show that, when the temperature is kept constant, an increase in air velocity increases the value of D_{eff}. Similar results were reported by Aghbashlo *et al*., (2008). Also, D_{eff} had a higher value in the treated barberries compared with the untreated ones.

Table 3. Effective moisture diffusivity and correlation for the performed experiments.

Code	Air temperature(ºC)	ν= 0.3 m s^{-1}	R^2	ν= 0.5 m s^{-1}	R^2	ν= 1 m s^{-1}	R^2
	60	2.57E-13	0.9633	4.92E-13	0.9429	5.35E-13	0.8946
NAT	70	1.03E-12	0.969	1.93E-12	0.9731	1.95E-12	0.9033
	80	3.95E-12	0.9388	5.03E-12	0.9056	6.42E-12	0.8618
E_1	60	4.48E-13	0.9886	5.77E-13	0.8787	1.26E-12	0.9838
	70	2.15E-12	0.8971	3.58E-12	0.9806	5.17E-12	0.891
	80	5.15E-12	0.8974	7.30E-12	0.8575	8.87E-12	0.9423
E_2	60	5.33E-13	0.871	6.62E-13	0.9028	2.00E-12	0.9725
	70	3.10E-12	0.9785	3.87E-12	0.9344	5.93E-12	0.9219
	80	4.77E-12	0.9358	7.72E-12	0.9202	9.67E-12	0.8781

Table4. Colour parameters in different drying conditions.

Drying condition	*L*	*a*	*b*	*ΔE*	*H* (degree)
NT1V1	2.44E1± 1.024^{h}	1.67E1±0.536^{c}	7.17E0±0.364^{cde}	6.03E0±0.752^{defg}	2.17E0±0.058^{cde}
NT1V2	2.25E1± 0.687^{cdef}	1.68E1±0.342^{c}	6.80E0±0.690^{bc}	7.07E0±0.842^{gh}	2.25E0±0.067^{efghi}
NT1V3	2.63E1± 1.127^{i}	1.88E1±0.173^{efg}	7.82E0±0.295^{def}	3.27E0±0.410^{a}	2.26E0±0.073^{efghi}
NT2V1	2.44E1± 0.335^{h}	2.03E1±1.028^{ghij}	9.79E0±0.803^{j}	3.88E0±0.435^{ab}	1.88E0±0.04^{a}
NT2V2	2.371E1± 2.048^{h}	1.96E1±1.629^{efghi}	9.07E0±1.215^{hij}	4.71E0±1.956^{bcd}	2.07E0±0.085^{bc}
NT2V3	2.28E1±0.304^{defg}	2.02E1±0.349^{fghi}	8.42E0±0.202^{fgh}	4.81E0±0.361^{bcde}	2.25E0±0.049^{efghi}
NT3V1	2.14E1± 1.205^{bc}	1.72E1±0.854^{de}	7.40E0±0.760^{cde}	6.98E0±1.513^{gh}	2.33E0±0.141^{ghi}
NT3V2	2.28E1± 0.310^{defg}	2.13E1±0.495^{jk}	8.92E0±0.362^{ghij}	4.66E0±0.284^{bcd}	2.25E0±0.049^{efghi}
NT3V3	2.27E1± 0.651^{cdefg}	2.00E1±0.691^{fghij}	8.67E0±0.623^{fgh}	5.09E0±0.737^{bcdef}	2.15E0±0.078^{bcde}
E1T1V1	2.18E1± 0.378^{bcd}	1.93E1±0.271^{efg}	7.82E0±0.191^{def}	6.13E0±0.448^{def}	2.33E0±0.067^{ghi}
E1T1V2	2.10E1± 0.445^{ab}	1.87E1±0.338^{def}	6,66E0±0.120^{bc}	7.27E0±0.266^{gh}	2.67E0±0.017^{k}
E1T1V3	2.31E1± 0.305^{defgh}	2.02E1±0.110^{fghij}	8.74E0±0.060^{fgh}	4.59E0±0.293^{abc}	2.17E0±0.008^{bcde}
E1T2V1	2.39E1± 0.932^{gh}	2.11E1±1.11^{ij}	8.87E0±0.497^{ghi}	3.72E0±0.927^{ab}	2.23E0±0.006^{defgh}
E1T2V2	2.31E1± 0.211^{defgh}	1.94E1±0.94^{efgh}	8.47E0±0.505^{fgh}	5.03E0±0.538^{bcde}	2.12E0±0.030^{bcd}
E1T2V3	2.23E1± 0.232^{bcde}	1.96E1±0.57^{efghi}	8.00E0±0.633^{efg}	5.62E0±0.448^{cdef}	2.34E0±0.113^{hi}
E1T3V1	2.35E1± 0.399^{efghs}	2.28E1±0.312^{l}	9.73E0±0.400^{ij}	4.37E0±0.438^{abc}	2.18E0±0.125^{cdef}
E1T3V2	2.26E1± 0.470^{cdefg}	2.11E1±0.862^{ijk}	9.16E0±0.368^{hij}	5.05E0±0.542^{bcde}	2.16E0±0.013^{bcde}
E1T3V3	2.37E1± 0.384^{fgh}	2.21E1±0.361^{kl}	8.80E0±0.202^{ghi}	3.74E0±0.338^{ab}	2.37E0±0.020^{ij}
E2T1V1	2.19E1±0.250^{bcd}	1.46E1±0.113^{b}	5.96E0±0.231^{b}	9.26E0±0.247^{i}	2.30E0±0.098^{fghi}
E2T1V2	2.01E1± 0.395^{a}	1.18E1±0.200^{a}	3.85E0±0.112^{a}	1.31E0±0.398^{j}	2.94E0±0.065^{l}
E2T1V3	2.19E1±0.440^{bcd}	1.72E1±0.905^{cd}	7.34E0±0.204^{cde}	7.13E0±0.931^{gh}	2.18E0±0.026^{cde}
E2T2V1	2.27E1±0.157^{cdefg}	2.09E1±0.200^{hijk}	9.32E0±0.287^{hij}	4.96E0±0.196^{bcde}	2.074E0±0.034^{bc}
E2T2V2	2.31E1±0.136^{defgh}	2.04E1±0.436^{ghij}	8.66E0±0.148^{fgh}	4.54E0±0.224^{abc}	2.22E0±0.006^{defg}
E2T2V3	2.19E1±0.270^{bcd}	1.67E1±0.540^{c}	6.64E0±0.113^{bc}	7.60E0±0.462^{h}	1.67E0±0.540^{i}
E2T3V1	2.20E1±1.01^{bcd}	2.20E1±1.181^{kl}	9.34E0±0.480^{hij}	5.66E0±0.836^{cdef}	2.20E0±1.181^{defgh}
E2T3V2	2.31E1±1.03^{defgh}	2.01E1±2.617^{fghij}	9.16E0±1.048^{hij}	5.31E0±0.880^{cdef}	2.01E0±2.617^{b}
E2T3V3	2.19E1±0.26^{bcd}	1.86E1±0.057^{def}	7.05E0±0.277^{cd}	6.43E0±0.218^{fgh}	1.86E0±.057^{j}

The values indicate mean ±standard deviation of three replications. Values within the same column with similar letters are not significantly different. N: no pretreatment, T1= 60ºC, T2= 70ºC, T3= 80ºC, V1= 0.3 m s^{-1}, V2= 0.5 m s^{-1}, V3= 1 m s^{-1}.

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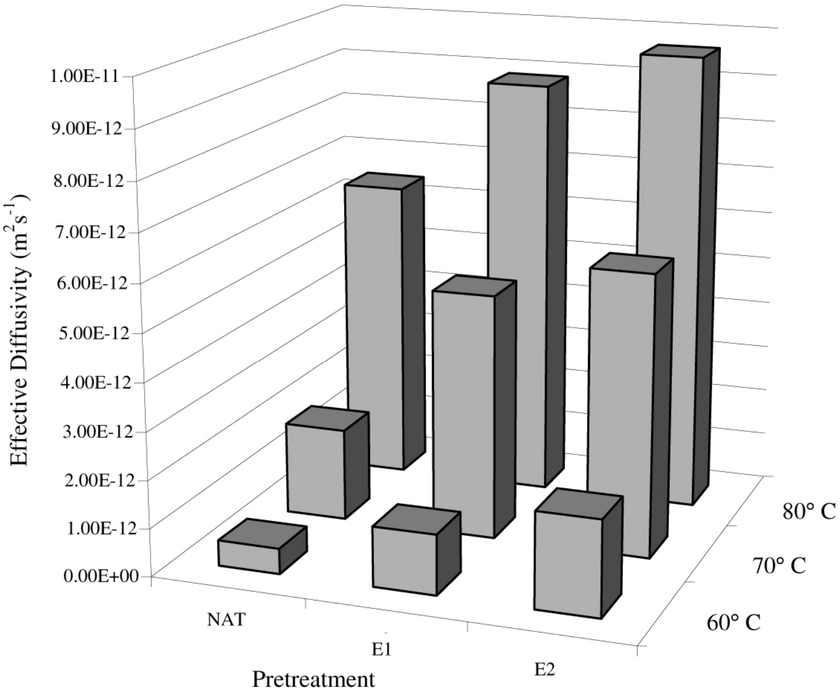

Figure 7. Variation of effective diffusivity (D_{eff}) at different drying temperature and constant air velocity of $1ms^{-1}$.

Barberries treated with olive oil and K_2CO_3 emulsion had the highest value of D_{eff}.

Colour Analysis

Colour is an important quality criterion in foods and agricultural products. Undesirable changes in colour of food may lead to a decrease in its quality and marketing value. In this study, the rates of browning reactions were not very different among the high and the low drying temperatures. Hence, colour differences were still small. The three colour parameters (L, a, and b) of the dried barberry samples in different drying conditions are shown in Table 4. Compared to the fresh fruit, ΔL and Δb of the dried barberries increased and this was more drastic in the higher temperatures. Despite this increase, Δa decreased. ΔL and Δb in the heat shocking samples were higher than Δa. The air temperature significantly affected Hunter colour values of barberries ($P \leq 0.05$), whereas the air velocity had no significant effect on colour values. Increase in browning with an increase in air temperature has been reported in the case of American ginseng by Ren and Chen (1998) and for garlic cloves by Sharma and Prasad (2001). In the samples treated with 3% olive oil and 6% K_2CO_3, ΔL and Δb values were high compared with the pretreated samples, but had a higher Δa. Final results showed higher colour changes in the barberries treated with 3% olive oil and 6% K_2CO_3 compared with the berries dipped in hot-water at 85ºC.

CONCLUSIONS

The kinetics of drying and colour changes of barberries during different drying conditions was investigated. The main conclusions are as follows:

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High temperatures and high air velocities enhanced the speed of drying, but the effect of temperature was more significant than that of the air velocity.

Pretreatments significantly changed the drying characteristics (kinetics) of barberries.

The most effective treatment to accelerate the drying process was the use of emulsion of 3% olive oil and 6% K_2CO_3 , at 50ºC, with immersion time of 2 minutes.

The air temperature significantly affected Hunter colour values of barberries, whereas the air velocity had no significant effect on the colour values.

Compared with the untreated barberries, the treated ones had higher colour changes.

Barberries treated with an emulsion of 3% olive oil and 6%K_2CO_3, at 50ºC, with immersion time of 2 minutes, had more colour differences other conditions.

The effective diffusivity was calculated from the data and varied from 2.57×10^{-13} m^2 s^{-1} for the untreated barberries to 9.67×10^{-12} m^2 s^{-1} for the barberries treated with olive oil and K_2CO_3 emulsion with the temperature and pretreatment dependence.

The increase in air temperature at constant air velocity increased the value of D_{eff} , as well as the increase in air velocity.

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سینتیک خشک شدن و کیفیت زرشک در خشک کن لایه نازک

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چکیده

هدف از این تحقیق، بررسی سینتیک خشک شدن زرشک (*Berberis vulgaris* L.) در دماهای مختلف (۶۰، ۷۰ و ۸۰ درجه سلسیوس)، سرعت هوای (۰/۳، ۰/۵ و ۱ متربرثانیه) و دو پیش‌تیمار است. زمان خشک‌شدن و تغییررنگ در طول خشک‌شدن از طریق آزمایش تعیین شد. زرشک‌ها از محتوای رطوبت اولیه ۷۳/۴۴٪ بر پایه‌تر به محتوای رطوبت مورد نیاز ۱۸٪ بر پایه‌تر در طول خشک شدن رسیدند. سینتیک خشک شدن توسط اندازه‌گیری وزن زرشک‌ها در فواصل زمانی منظم، تحت نظارت قرارگرفت. منحنی‌های خشک شدن برای زرشک‌های شاهد و تیمار شده به‌دست آمدند. تاثیر دو پیش‌تیمار روی سینتیک خشک‌شدن مورد بررسی قرار-گرفت. دو پیش تیمار شامل شوک حرارتی با فرو بردن دانه های زرشک در آب داغ و فرو بردن آن بلافاصله در آب سرد و دیگری فرو بردن آنها در امولسیون شامل روغن زیتون و کربنات پتاسیم خوراکی بود. رنگ محصول در طول خشک شدن تغییر کرد. نتایج نشان داد که استفاده از دماهای پایین مانع از این تغییر رنگ می-شود. دمای هوا روی سرعت خشک شدن و مقادیر رنگ در مقیاس هانترلب در سطح معنی دار ۵٪ تاثیرگذار بود. استفاده از شوک حرارتی و امولسیون روغن زیتون و کربنات پتاسیم زمان خشک شدن را به ترتیب ۴۰٪ و ۶۰٪ کاهش داد. انتقال رطوبت از نمونه‌ها توسط مدل انتشار فیک بیان شد تا ضریب پخش موثر(D_{eff}) محاسبه شود. این ضریب با افزایش دما افزایش یافت و مقادیر بزرگتری برای نمونه‌های تیمار شده به‌دست آمد. همچنین مقادیر بزرگتری برای نمونه‌های تیمار شده با امولسیون شامل روغن زیتون و کربنات پتاسیم نسبت به نمونه تیمار شده با آب داغ به‌دست آمد. مقادیر ضریب پخش نمونه‌های شاهد و تیمارشده به ترتیب $۲/۵۷\times۱۰^{-۱۳}$ و $۹/۶۷\times۱۰^{-۱۲}$ بود. تغییر رنگ کلی (ΔE) و زاویه رنگ (H) با افزایش دما افزایش یافت. در نمونه‌های تیمار شده با امولسیون تغییر رنگ بیشتری مشاهده شد. تحلیل آماری نشان داد که دما و پیش تیمار بیشترین تاثیر را در کاهش زمان خشک‌شدن در سطح معنی‌دار ۱٪ داشته است.

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