Effect of blanching on thin layer drying kinetics of aonla (*Emblica officinalis*) shreds

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Revised: 19 December 2011 / Accepted: 24 January 2012 / Published online: 15 February 2012
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Abstract The effect of hot water blanching treatment on thin layer drying kinetics of aonla shreds was studied at drying air temperatures of 50, 55 and 60 °C with the air velocity of 1.2 m/s. The drying time decreased with the increase in air temperature and blanching. The drying process was observed in falling rate. Drying after blanching reduced the vitamin C content of aonla shreds by 69.36% whereas it decreased by 27.78% in unblanched shreds. Eight commonly used mathematical models were evaluated to predict the drying behavior of aonla shreds. The Midilli model described the drying behaviour of unblanched aonla shreds at all temperatures better than other models whereas two-term model described the drying kinetics of blanched aonla shreds satisfactorily. The effective diffusivities of the unblanched and blanched aonla shreds were determined using Fick's law of diffusion. The activation energy was found to be 47.21 kJ/mol for unblanched and 43.98 kJ/mol for blanched aonla shreds.

Keywords Aonla shreds · Blanching · Drying kinetics · Diffusion · Activation energy

Introduction

The Aonla (*Emblica officinalis*) is an important fruit crop of tropical and subtropical region of India. It is used in traditional Indian medicine systems, like *ayurvedic* and *unani*

owing to its therapeutic values (Agrawal and Chopra 2004). Dry aonla shreds are used for treatment of common cold, gastric troubles, headache, constipation, enlarged liver etc. (Goyal et al. 2008). Besides, it is used in cosmetics for enriching hair growth. It is the richest source of ascorbic acid (vitamin C) among fruits and also contains tannin, polyphenol, pectin, gallic acid and fiber. About 600–900 mg of vitamin C is found in 100 g of aonla pulp (Pokharkar 2005).

Sour and astringent taste of aonla fruits demands its processing to improve taste and acceptability. This fruit has great potential for processing into value added products for national as well as in international markets. Value addition of aonla has increased many folds owing to demand of its processed products as well as increase in crop production in recent years.

Hot-air drying is one of the most widely used methods for the preservation of food in commercial processing. Drying is done to decrease the water activity of the products, inhibiting development of microorganisms and decreasing spoilage reactions to prolong the shelf life. Added advantages of dehydrated products include reduction in costs of packaging, storage and transportation due to reduced bulk and mass of the dried product (Okos et al. 1992). Furthermore, products with low moisture contents may be stored for long duration at normal environmental conditions (Jarayaman and Das Gupta 1995).

Several phenomena related to heat and mass transfers are involved in the drying process. The kinetics of mass transfer (mainly water) during drying process depends on temperature, relative humidity, air flow rate, product thickness, load density and shape of product (Olivas et al. 1999). The predominant mechanism in food drying process is diffusion of water from as well as within the food to the surface in contact with drying air. Modeling of the drying process is an

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efficient tool for prevention of product deterioration, energy consumption, equipment stress and product yields (Olivas et al. 1999). Number of empirical equations has been proposed to describe drying process, modeling its kinetics and design of drying systems (Kiranoudis et al. 1992). All these equations derive a direct relationship between change in moisture content and drying time, and are strongly related to Fick's second law of diffusion (Akpınar 2006).

Improvement in quality of dried products can be achieved with various pre-treatments like blanching before drying, treatment with antioxidants etc. Blanching in hot water along with additives like sodium/potassium metabisulphite (0.1–0.5%), sodium chloride (3%) etc. is one of the most widely used pre-treatment given to the fruits prior to the drying. It inactivates enzymes, changes in tissue structure, reduces drying time and increases drying rate (Severini et al. 2003; Kadam et al. 2006). Pragati et al. (2003) studied effect of drying methods on nutritional composition of dehydrated aonla fruit during storage. Gudapathy et al. (2010) studied the quality characteristics of pre-treated aonla fruits dried in an LPG operated drier.

Therefore, the present study was done with an objective to study and model the effect of blanching on the kinetics of hot-air drying of aonla shreds and to evaluate the effect of temperature and blanching on the diffusion coefficient and activation energy.

Materials and methods

Procurement of aonla fruits

The aonla fruits (cultivar NA-7) were procured from the orchards of Central Institute of Postharvest Engineering and Technology, Abohar (Punjab, India). The injured, damaged and immature fruits were separated and the lot was washed using normal tap water. The surface moisture of the fruits was removed using tissue paper and fruits were stored at 15 ± 1 °C in a cold room for overnight to minimize deterioration prior to preparation of shreds. The fruits were taken out from cold room and kept under ambient conditions for two hours prior to conducting experiments and then graded. Only sound and uniform size graded fruits were taken for the experiments.

Preparation and pretreatment of aonla shreds

The aonla shreds (5 mm wide $\times$ 3 mm thick) were prepared manually using domestic fruit shredder. The shreds were then blanched in 0.3% KMS (potassium metabisulphite) solution for 3 min at 80 °C (product-solution ratio was 1:5 w/w). After blanching, the excess solution was removed and the shreds were kept for drying at desired conditions.

Drying of aonla shreds

Drying studied of aonla shreds was conducted in the temperature range of 50–60 °C. Since blanching affects the vitamin C content adversely, this range of temperature was selected to minimize the loss of vitamin C. The moisture contents of the blanched and unblanched shreds prior to and after drying were determined using hot air oven method (Ranganna 2002). The drying of shreds was done in cabinet tray dryer. The dryer consisted of 24 aluminum trays (800 mm $\times$ 400 mm $\times$ 30 mm size) with temperature control in the range of above ambient to 300 ± 1 °C. It was equipped with a centrifugal fan for air circulation inside the drying chamber with 1.2 m/s speed.

Prior to drying of shreds (unblanched and blanched), the dryer was set to required drying temperatures ($50\text{--}60 \pm 1$ °C). After reaching to the preset temperature, the dryer was kept on for 1 h without samples to achieve uniform temperature in all inner parts of dryer. About 5 kg aonla shred samples were weighed using electronic balance (least count ± 0.1 g; capacity 10 kg; M/s Swastik, Ludhiana, India). Then shreds were uniformly spread on pre-weighed trays of about 5 mm thickness and loaded in the dryer running at desired drying temperature (50–60 °C). Remaining trays were also filled with aonla shreds, but the weight was not measured. The heat load of the dryer was 0.41 kWh/kg material. The trays were taken out from the dryer after every 30 min and weighed and the tray with samples transferred to the dryer immediately. The drying continued till the change in mass was less than 0.1%. Each experiment replicated thrice. The vitamin C content of aonla shreds prior to blanching, after blanching and after drying was measured by 2,6 dichlorophenol indophenol method (Ranganna 2002).

Modelling of drying kinetics

Nine commonly used empirical models, as given in Table 1 were evaluated to describe the drying kinetics of aonla shreds. In these models, MR represents the dimensionless moisture ratio, which is defined as

$$MR = (M - M_e) / (M_0 - M_e) \quad (1)$$

where M is the moisture content (% dry basis) of the product after time t (min), M_0 is the initial moisture content of the product (% d.b) and M_e is the final moisture content (% d.b).

The values of M_e are relatively small as compared with M or M_0 for long drying time. Thus, $MR = (M - M_e) / (M_0 - M_e)$ can be simplified to $MR = M / M_0$ (Akgun and Doymaz 2005; Thakor et al. 1999).

The non-linear least square regression analysis using Statistica version 6 software was done to compute the regression coefficients of the model. The quantitative error

Table 1 Mathematical models given by various authors for drying curves

S.No.	Model name	Model	References
1	Lewis	$MR = \exp(-kt)$	Bruce (1985)
2	Page	$MR = \exp(-kt^n)$	Bruce (1985)
3	Modified Page	$MR = \exp(-kt)^n$	Ozdemir and Devres (1999)
4	Henderson and Pabis	$MR = a \cdot \exp(-kt)$	Yagcioglu (1999)
5	Logarithmic	$MR = a \cdot \exp(-kt) + c$	Yaldiz and Ertekin (2001)
6	Two-term model	$MR = a \cdot \exp(-k_0t) + b \cdot \exp(-k_1t)$	Rahman et al. (1998)
7	Two term exponential	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-kat)$	Yaldiz and Ertekin (2001)
8	Midilli et al.	$MR = a \cdot \exp(-kt^n) + bt$	Midilli, et al. (2002)

Where a , b , c , k , k_0 and k_1 are characteristic constants of different models; and t is drying time (min).

parameters were used to ascertain the ability of models to describe drying kinetics. The residual sum of squares (RSS) is an important parameter during non-linear curve fitting defined as:

$$RSS = \sum_{i=1}^n (MR - MR_{cal})^2 \quad (2)$$

where MR is the measured value, MR_{cal} is the value estimated through the fitting equation and n is the number of data points.

The standard error of estimate (SEE) indicates the fitting ability of a model to a set of data. The SEE represents the deviation of dependent variable MR , which is defined as

$$SEE = \sqrt{\sum_{i=1}^n \frac{(MR - MR_{cal})^2}{df}} \quad (3)$$

However, the SEE indicates the fitting ability of equation only and can not provide direct visualization of goodness of fit of the equation. The mean relative deviation modulus (MRD) was used to describe the goodness of fit of the models, which is defined as

$$MRD = \frac{1}{n} \sum_{i=1}^n \frac{|MR - MR_{cal}|}{MR} \quad (4)$$

Estimation of effective diffusivities

Fick's second law of diffusion was applied to describe the mass transfer by diffusion which uses the relationship established on moisture (MR) as a dependent variable described in Eq. 5, and which relates the gradient of sample moisture in real time with the initial moisture and the equilibrium moisture (Akpınar et al. 2003; Babalis and Belessiotis 2004; Simal et al. 2005). In this experiment, the integrated equation for long time periods and infinite slab geometry was used, representing the first term of the development of the series Eq. 5 in Eq. 6 (Crank 1975), with which the diffusivity

coefficient (D_{eff}) was obtained for each temperature under study

$$MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp \left[\frac{(-2n+1)^2 D_{eff} \pi^2 t}{4L^2} \right] \quad (5)$$

$$MR = \frac{8}{\pi^2} \exp \left[\frac{-D_{eff} \pi^2 t}{4L^2} \right] \quad (6)$$

where D_{eff} is the effective diffusivity (m^2/s); L is the half thickness of slab (m).

Estimation of activation energy

The temperature dependence of the effective diffusivity may be described by an Arrhenius-type relationship (Akgun and Doymaz 2005; Madamba et al. 1996; Ozdemir and Devres 1999; Sanjuan et al. 2003) as follows:

$$D_{eff} = D_0 \exp \left(-\frac{E_a}{RT} \right) \quad (7)$$

where D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s), E_a is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol K), and T is the absolute temperature (K). From the slope of the straight line of $\ln D_{eff}$ versus reciprocal of T , described by the Arrhenius equation, the activation energy, E_a , was estimated using above expression.

Results and discussion

Effect of blanching and drying on Vitamin C content of aonla shreds

The initial vitamin C content of aonla shreds was 360 ± 14.5 mg/100 g. After blanching, the vitamin C content was 260 ± 10.5 mg/100 g, and 27.78% reduction was observed. In unblanched samples, the minimum vitamin C content of

320±15.14 mg/100 g was observed after drying at 60 °C. It indicated that the vitamin C present in the aonla was quite stable and increase in drying temperature resulted in higher loss of vitamin C. However, the drying of unblanched aonla shreds may be done safely up to 60 °C. Further the vitamin C content of blanched aonla shreds were 122.42±8.91, 118.21±12.14 and 110.32±7.68 mg/100 g after the completion of drying at 50, 55 and 60 °C. Thus, more than 50% vitamin present in the blanched sample was destroyed. It showed that the drying of aonla shreds after blanching has deleterious effect on vitamin C content. Therefore, the drying of aonla shreds may not be recommended after blanching.

Drying characteristics of aonla shreds

The unblanched aonla shreds and blanched aonla shreds were dried in the cabinet tray drier. Changes in moisture ratio of unblanched and blanched shreds with time of drying are shown in Fig. 1. It can be observed from Figure that the drying rate increased with temperature for both samples. The constant rate drying period was not observed owing to very high initial water content and drying took place in the falling rate period. This result was in agreement with previous studies on drying of foods (Akpınar et al. 2004; Ghodake et al. 2006; Singh et al. 2006; Kaya et al. 2007; Sobukola et al. 2007). It showed that diffusion was the most likely physical mechanism governing moisture movement in aonla shreds. Blanching of aonla shreds reduced the time required for drying (Fig. 1 a & b). It might be due to the disruption of cell walls of shreds during blanching and the water diffusion rate increased. Kingsly et al. (2007) Ertekin and Yaldiz (2004) reported similar results for tomato and egg plant. The blanching decreased the drying time by 8–13% compared to unblanched aonla shreds.

Fitting the models of drying kinetics

The drying rate data of aonla shreds (unblanched and blanched) were fitted to the eight selected models (Table 1) and evaluated for their ability to predict the moisture diffusion behaviour. The results of the analysis are given in Tables 2 and 3. The R^2 value for all the models was observed as 0.99. The Lewis model, Page model, modified Page model, Henderson & Pabis model and two term exponential model did not describe the drying kinetics of aonla shreds due to high SEE and MRD values (Table 3). Two term model did not describe the drying kinetics of unblanched aonla shreds. However it described the drying kinetics of blanched aonla shreds better than other models under study. The MRD and SEE values obtained from the analysis indicated that Midilli's model described the drying behaviour of both unblanched aonla

Fig. 1 Thin layer drying curves of aonla shreds at different temperatures (a) unblanched; (b) blanched

shreds satisfactorily and better than all other models evaluated. Similar results were reported for thin layer drying of kiwi fruits (Mohammadi et al. 2009) and apples (Meisami et al. 2009). The scattered residual values of two term model for blanched samples and Midilli's model for unblanched samples indicated that these models might be used to describe the drying kinetics of blanched and unblanched aonla shreds, respectively.

Effective diffusivities

The effective diffusivities (D_{eff}) at different drying temperatures were estimated using Fick's law (Eqs. 5 and 6). The effective diffusivities at different temperatures of unblanched and blanched aonla shreds are given in Table 4. In general the effective diffusivity of the food materials ranges from 10^{-11} to 10^{-9} m²/s for food materials (Madamba et al. 1996). The effective diffusivities varied from $1.02\text{--}1.73 \times 10^{-10}$ for unblanched and $1.29\text{--}2.1 \times 10^{-10}$ for blanched aonla shreds respectively. The blanching of shreds ruptured the cell walls which resulted in high internal mass transfer during drying and had higher moisture diffusivities. Similar results of

Table 2 Values of statistical parameters

Model	Drying temperature (°C)	Pretreatment	RSS	SEE	MRD
Lewis	50	Unblanched	2.85×10^{-3}	1.88×10^{-2}	11.38
	55		1.78×10^{-3}	1.59×10^{-3}	17.94
	60		1.01×10^{-5}	1.42×10^{-3}	14.63
	50	Blanched	2.81×10^{-3}	1.82×10^{-2}	24.15
	55		3.49×10^{-3}	2.23×10^{-2}	31.25
	60		1.39×10^{-3}	1.66×10^{-2}	26.04
Page	50	Unblanched	1.63×10^{-3}	1.51×10^{-2}	14.35
	55		1.58×10^{-3}	1.62×10^{-2}	15.25
	60		1.11×10^{-4}	5.33×10^{-3}	5.64
	50	Blanched	9.31×10^{-4}	1.15×10^{-2}	12.21
	55		1.09×10^{-3}	1.34×10^{-2}	15.99
	60		7.91×10^{-4}	1.40×10^{-2}	15.54
Modified Page	50	Unblanched	2.85×10^{-3}	2.01×10^{-2}	11.38
	55		1.78×10^{-3}	1.72×10^{-2}	17.94
	60		1.01×10^{-3}	1.59×10^{-2}	3.77
	50	Blanched	2.76×10^{-3}	1.98×10^{-2}	24.15
	55		3.49×10^{-3}	2.41×10^{-2}	31.25
	60		1.39×10^{-3}	1.86×10^{-2}	26.04
Henderson and Pabis	50	Unblanched	2.53×10^{-3}	1.90×10^{-2}	11.65
	55		1.78×10^{-3}	1.72×10^{-2}	17.89
	60		9.61×10^{-4}	1.55×10^{-2}	14.17
	50	Blanched	2.64×10^{-3}	1.94×10^{-2}	23.46
	55		3.38×10^{-3}	2.37×10^{-2}	30.65
	60		1.38×10^{-3}	1.85×10^{-2}	25.89
Logarithmic	50	Unblanched	2.53×10^{-3}	2.05×10^{-2}	11.13
	55		5.61×10^{-4}	1.05×10^{-2}	5.08
	60		1.61×10^{-4}	7.39×10^{-3}	2.82
	50	Blanched	1.01×10^{-4}	4.11×10^{-3}	3.52
	55		1.21×10^{-4}	4.99×10^{-3}	5.35
	60		1.52×10^{-4}	7.08×10^{-3}	4.37
Two term	50	Unblanched	2.54×10^{-3}	2.25×10^{-2}	11.65
	55		4.28×10^{-4}	1.03×10^{-2}	5.87
	60		9.01×10^{-5}	6.84×10^{-3}	4.13
	50	Blanched	4.02×10^{-5}	2.81×10^{-3}	1.07
	55		3.03×10^{-5}	2.54×10^{-3}	1.55
	60		1.52×10^{-4}	8.66×10^{-3}	4.17
Midilli	50	Unblanched	1.04×10^{-4}	4.02×10^{-3}	2.40
	55		2.09×10^{-4}	7.22×10^{-3}	5.19
	60		4.10×10^{-5}	4.51×10^{-3}	2.61
	50	Blanched	1.32×10^{-4}	5.13×10^{-3}	3.59
	55		1.41×10^{-4}	5.94×10^{-3}	5.20
	60		1.85×10^{-4}	9.61×10^{-2}	6.72
Two term exponential	50	Unblanched	1.73×10^{-3}	1.57×10^{-2}	15.07
	55		1.20×10^{-3}	1.41×10^{-2}	11.99
	60		1.01×10^{-3}	1.20×10^{-2}	10.24
	50	Blanched	5.15×10^{-4}	8.57×10^{-3}	9.90
	55		3.49×10^{-3}	2.41×10^{-2}	31.25
	60		1.04×10^{-3}	1.21×10^{-2}	14.10

RSS Residual sum of squares;
 SEE Standard error of estimate;
 MRD mean relative deviation
 modulus

Table 3 Constants of different models

Model	Drying temp. (°C)	Pretreat-ment	Constants						k ₀	k ₁
			k	n	a	b	c			
Lewis	50	T ₁	0.01							
	55		0.01							
	60		0.02							
	50	T ₂	0.02							
	55		0.02							
	60		0.02							
Page	50	T ₁	0.01	1.08						
	55		0.02	0.96						
	60		0.03	0.91						
	50	T ₂	0.03	0.89						
	55		0.04	0.86						
	60		0.04	0.91						
Modified Page	50	T ₁	0.01	1.13						
	55		0.71	0.02						
	60		0.15	0.16						
	50	T ₂	0.35	0.05						
	55		1.05	0.02						
	60		0.03	1.00						
Henderson and Pabis	50	T ₁	0.01		1.02					
	55		0.02		0.99					
	60		0.02		0.99					
	50	T ₂	0.02		0.98					
	55		0.02		0.98					
	60		0.03		0.99					
Logarithmic	50	T ₁	0.01		1.01		1.57×10 ⁻³			
	55		0.02		0.98		0.02			
	60		0.02		0.97		0.02			
	50	T ₂	0.02		0.96		0.03			
	55		0.02		0.96		0.03			
	60		0.03		0.97		0.02			
Two term	50	T ₁			0.92	0.09		0.01	0.01	
	55				3.59×10 ⁻³	1.00		8.64×10 ⁻³	0.02	
	60				0.35	0.65		0.01	0.03	
	50	T ₂			0.07	0.92		3.85×10 ⁻³	0.02	
	55				0.08	0.96		4.47×10 ⁻³	0.03	
	60				0.97	0.02		0.03	4.64×10 ⁻³	
Midilli	50	T ₁	6.62×10 ⁻³	1.17	0.99	1.29×10 ⁻⁴				
	55		0.01	1.05	1.00	1.47×10 ⁻⁴				
	60		0.03	0.93	0.99	5.91×10 ⁻⁵				
	50	T ₂	0.02	0.95	1.00	9.41×10 ⁻⁵				
	55		0.02	0.93	1.00	1.14×10 ⁻⁴				
	60		0.03	0.99	1.00	1.37×10 ⁻⁴				
Two term exponential	50	T ₁	0.01		1.55					
	55		0.02		0.56					
	60		0.02		0.99					
	50	T ₂	0.03		0.44					
	55		0.02		1.00					
	60		0.26		0.09					

^a T₁- Unblanched aonla shreds and T₂ – Blanched aonla shreds

Table 4 Effective diffusivities of unblanched and blanched aonla shreds dried at different temperatures

Drying temperature (°C)	D_{eff} (m ² /s)	
	Unblanched	Blanched
50	1.02×10^{-10}	1.29×10^{-10}
55	1.28×10^{-10}	1.63×10^{-10}
60	1.73×10^{-10}	2.11×10^{-10}

influence of blanching pretreatments on moisture diffusivity during air drying were reported in apricots (Pala et al. 1996).

Activation energy

Arrhenius-type equation was used to calculate activation energy. The natural logarithm of D_{eff} as a function of the reciprocal of absolute temperature was plotted for unblanched and blanched samples (Fig. 2). The result showed a linear relationship for both with R^2 value 0.99 for blanched and unblanched aonla shreds. Activation energy was calculated from slope of lines. The activation energy of unblanched and blanched shreds was 47.21 kJ/mol and 43.98 kJ/mol respectively. The estimated activation energy of both samples were found within the range (12.87–58.15 kJ/mol) of activation energies reported by Senadeera et al. (2003) for other high moisture foods.

Conclusion

The unblanched and blanched aonla shreds were dried in cabinet tray dryer which took place in the falling rate drying period. Drying kinetics of aonla shreds was affected by air temperature and blanching. The total drying time of aonla shreds decreased whereas the effective diffusivity increased with increase in drying air temperature. The total drying

time was decreased in the range of 8–13% by blanching as compared to unblanched aonla shreds. Drying aonla shreds after blanching resulted in more than 69% loss of vitamin C whereas drying of unblanched samples resulted in 27.78% loss of vitamin C at 60 °C. Therefore the drying of aonla shreds after blanching may not be recommended. Eight drying models were fitted to the experimental data out of which, the Midilli's model described results better than the other models for unblanched aonla shreds whereas two-term model described the drying kinetics of blanched aonla shreds satisfactorily. Arrhenius-type equation was used to estimate activation energy of unblanched and blanched aonla shreds, which were 47.21 kJ/mol for unblanched samples and 43.98 kJ/mol for blanched samples respectively.

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Fig. 2 Arrhenius plot for activation energy

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