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Thin-layer Drying Behaviour of Organically Produced Tomato

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Abstract: Drying kinetics of organically produced tomato slice was studied in a conventional hot-air dryer. The samples were dried at 50, 60 and 70°C air temperature with control and blanching as pretreatments. Drying of tomato occurred in falling rate period. Eight thin layer drying models were evaluated by fitting to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of organic tomato slices with high r^2 values. The effective moisture diffusivity of tomato samples increased as the drying air temperature was increased. Also the moisture diffusivity and activation energy were higher for blanched samples.

Key words: Organic tomato, drying, diffusivity, activation energy

Introduction

Tomato is one of the world's largest vegetable crops next only to potato and is available round the year. Organically produced tomatoes are in higher demand recently due to the belief of consumers that they are highly nutritive and have better taste (Woese *et al*., 1997). Organic production of tomato has attracted premium price and brings a 10-30% higher price than the conventionally produced tomatoes. As a processing crop, it ranks first among the vegetables (Ilyas *et al*., 2003). Ripe tomato fruit is consumed fresh and utilized in the manufacture of a range of processed products such as puree, paste, powder, ketchup, sauce, soup and canned whole fruits. Tomatoes are important source of lycopene and vitamin C and are valued for their colour and flavour. Dried tomatoes are rich in flavour, minerals and fibre. Commercially dried tomatoes are used in the preparation of sauce, powder, etc.

Drying involves the removal of moisture contained in the fruits or vegetables in order to preserve. Although preservation for enhanced shelf life is the primary reason for drying, it also lowers the product mass and volume. The reduction in mass and volume improves the efficiency of packaging, storing and transportation. Traditionally fruits and vegetables are dried in open sunlight, which is weather dependable and also prone to microbial and other contamination. To get best quality dried product hot air industrial dryers should be used. Industrial dryers are rapid and provide uniform, hygienic dried product (Doymaz and Pala, 2002). Also, blanching of vegetables prevents loss of colour by inactivating enzymes, reduces drying time by relaxing tissue structure and yield a good quality dried product (Piga *et al*., 2004).

The drying kinetics of vegetables is a complex phenomenon and requires simple representations to predict the drying behaviour and for optimizing the drying parameters. Thin layer drying equations has been used for drying time prediction and for generalization of drying curves (Karathanos and Belessiotis, 1999). Extensive research in drying behaviour of vegetables was reported (Hawlader *et al*., 1991; Rapuscas and Driscoll, 1995; Methakhup *et al*., 2005; Tunde-Akintunde *et al*., 2005; Kaleemullah and Kailappan, 2006; Akanbi *et al*., 2006; Kumar *et al*., 2006). But, no detailed studies

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were found in literature on drying kinetics of organically produced tomato. The objectives of this study were: i) to study the drying kinetics of organically produced tomato ii) to calculate the effective moisture diffusivity and activation energy during the drying process.

Materials and Methods

Experimental Material

Tomato, grown in the organic system of cultivation (cv. *Naveen*), was procured from the experimental farm of CIPHET, Abohar, Punjab, India for the experiments. Matured and firm tomatoes were selected from the whole lot. The initial moisture content of tomato was 1350.80% d.b. and was determined by the AOAC method No. 934.06 (AOAC, 2000). Tomatoes were sliced uniformly (average thickness: 4.3±0.5 mm) and were dried on the same day.

Drying Equipment

The drying experiments were conducted in a cabinet dryer (Narang Scientific Works, New Delhi). Overall dimensions of the dryer are, height: 1.48 m, width: 1.02 m and depth: 1.12 m. The dryer consisted of trays (800×400×30 mm), temperature controller (0-300°C, dry bulb temperature, accuracy ±1°C) and a centrifugal fan for airflow (1.2 m sec^{-1}).

Drying Procedure

Tomato slices were dried with pretreatments namely control (untreated sample) and blanching (70°C for 2 min). Drying experiments were conducted at 50, 60 and 70°C (±1°C). The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. Tomato slices (1000 g) were uniformly spread in rectangular aluminium trays and loaded in the dryer. Moisture loss was recorded at 30 min interval by a digital balance of 0.01 g accuracy. The drying was continued till the final moisture content reached 10±0.5% d.b. Experiments were replicated three times to minimize error.

Evaluation of Thin Layer Drying Models

Moisture ratio of samples during drying was expressed by the following equation:

$$MR = (M - M_e) / (M_o - M_e) \tag{1}$$

where MR is the dimensionless moisture ratio; M is the moisture content at time t and M_o and M_e, the initial and equilibrium moisture contents, respectively, on dry basis.

The moisture ratio was simplified according to Pala *et al.* (1996), since the MR values are relatively smaller when compared to M and M_o, to :

$$MR = M / M_O \tag{2}$$

Moisture ratio data was fitted with eight thin layer drying equations (Table 1) to select a suitable model for describing the drying process of tomato slices. Non-linear regression analysis was performed using SPSS (Statistical Package for Social Science) 11.5.1 program. Coefficient of correlation, r^2 was one of the main criteria for selecting the best model. In addition to coefficient of correlation, the goodness of fit was determined by various statistical parameters such as reduced chi-square, χ^2, mean bias error, MBE and root mean square error, RMSE. For quality fit, r^2 value should be higher and χ^2, MBE and RMSE values should be lower (Togrul and Pehlivan, 2002; Erenturk *et al*., 2004). The above parameters can be calculated as follows:

Table 1: Thin layer drying models

Equation	Name	References
$MR = \exp(-kt)$	Newton	Liu and Bakker-Arkema (1997)
$MR = \exp(-kt^n)$	Page	Zhang and Litchfield (1991)
$MR = \exp(-(kt)^n)$	Modified Page	Overhults *et al.* (1973)
$MR = a \exp(-kt)$	Henderson and Pabis	Henderson and Pabis (1961)
$MR = a \exp(-kt) + c$	Logarithmic	Yaldiz *et al.* (2001)
$MR = 1 + at + bt^2$	Wang and Singh	Wang and Singh (1978)
$MR = a \exp(-k_0 t) + b \exp(-k_1 t)$	Two-term	Rahman *et al.* (1998)
$MR = a \exp(-k t) + (1-a) \exp(-k a t)$	Two-term exponential	Sharaf-Eldeen *et al.* (1980)

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{exp.i} - MR_{pre.i})^2}{N - z} \tag{3}$$

$$MBE = \frac{1}{N} \sum_{i=1}^{N} (MR_{pre.i} - MR_{exp.i}) \tag{4}$$

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

where N is the total number of observations, z, the number of drying constants, $MR_{exp.i}$ the experimental values and $MR_{pre.i}$ the predicted moisture ratio values.

Calculation of Moisture Diffusivity and Activation Energy

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity by method of slopes. Since the tomato was dried after slicing, the samples were considered of slab geometry. The equation is expressed as (Maskan *et al.*, 2002):

$$M_R = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{L^2} \right) \tag{6}$$

where MR is the dimensionless moisture ratio, D_{eff} the effective moisture diffusivity in m^2/s, t-time of drying in seconds and L slab thickness in meters.

The activation energy for diffusion was estimated using simple Arrhenius equation as given below (Kaleemullah *et al.*, 2006):

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

where D_0 is the constant equivalent to the diffusivity at infinitely high temperature ($m^2 \sec^{-1}$), E_a the activation energy (kJ/mol), R the universal gas constant (8.314×10^{-3} kJ/mol K) and T is the absolute temperature (K). E_a was determined by plotting ln (D_{eff}) versus 1/T.

Results and Discussion

Drying Characteristics of Organic Tomato in a Convective Dryer

It is evident that the drying air temperature has an important effect on drying. When the temperature was increased, due to the quick removal of moisture, the drying time reduced (Table 2). The results are similar with the earlier observations on drying of garlic slices (Madamba *et al.*, 1996) and onion slices (Sarsavadia *et al.*, 1999).

Curves of moisture ratio versus drying time for the samples dried at different temperature and treatment are shown in Fig. 1-3. The moisture ratio decreased continuously with drying time and drying rate increased with the increase in temperature. Drying of tomato slices occurred in falling rate period and due to quick removal of moisture, no constant rate period was observed. Similar drying behaviour has been reported for red chillies (Chandy *et al*., 1992) and onion slices (Rapusas *et al*., 1995). The drying in falling rate period shows that, internal mass transfer has occurred by diffusion.

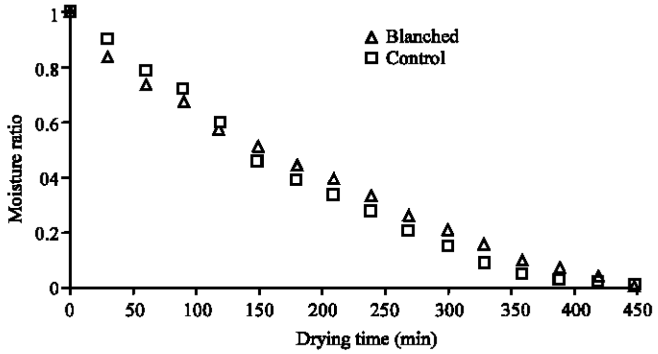

Fig. 1: Moisture ratio of tomato slices dried at 50°C

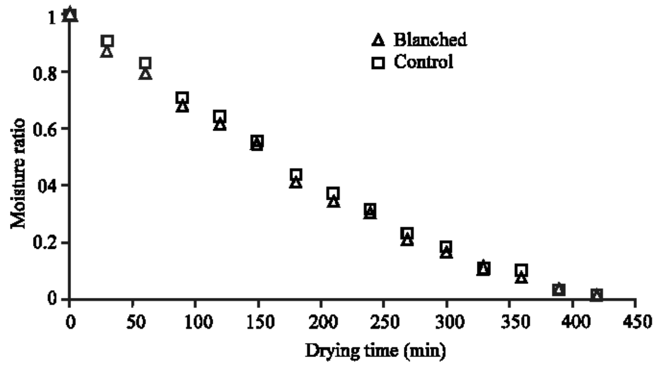

Fig. 2: Moisture ratio of tomato slices dried at 60°C

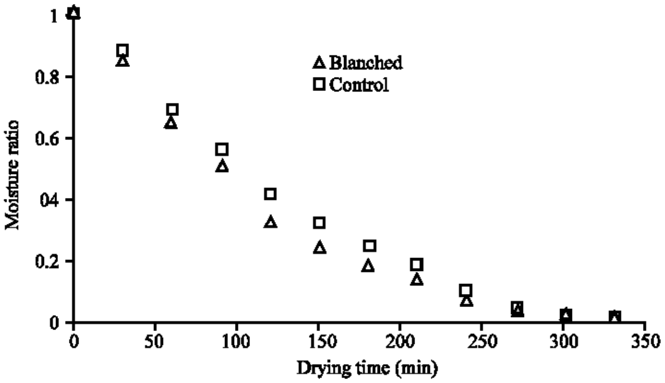

Fig. 3: Moisture ratio of tomato slices dried at 70°C

Selection of Thin-layer Drying Model

The coefficient of correlation of the thin-layer drying models (Table 1) fitted with moisture ratio data and results of statistical analyses are listed in Table 3. In all cases, the r^2-values for the mathematical models were greater than 0.90, indicating a good fit. However, values of r^2 for the Page, Wang and Singh and logarithmic model were above 0.99. But, the χ^2, MBE and RMSE values were lower when the values were fitted in the logarithmic model. Thus the logarithmic model may be assumed to represent the thin layer drying behaviour of organically produced tomato slices. Similar findings were reported for hot air drying of apricots (Togrul *et al*., 2002) and rosehip (Erenturk *et al*., 2004) and plum slices (Goyal *et al*., 2006). Accuracy of the selected model was compared by plotting the experimental moisture ratio and the predicted values from the logarithmic model (Fig. 4). The banding of predicted values around the straight line indicates the suitability of logarithmic model for describing the drying character of organically produced tomato.

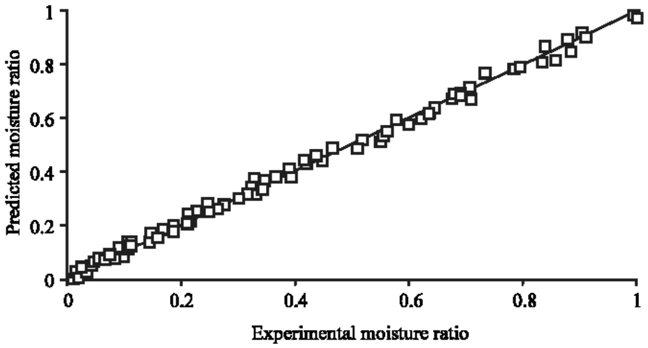

Fig. 4: Comparison of experimental moisture ratio and predicted values by the logarithmic model

Table 2: Drying time of tomato slices

Drying temperature (°C)	Pretreatment	Drying time (min)
50	Control	450
	Blanched	450
60	Control	420
	Blanched	420
70	Control	330
	Blanched	330

Table 3: Values of statistical parameters

Model	Drying temperature (°C)	Pretreatment	r^2	χ^2	RMSE	MBE
Newton	50	Control	0.9633	0.00407	0.061802	0.002849
		Blanched	0.9730	0.00251	0.048513	0.005865
	60	Control	0.9536	0.00502	0.068430	0.000162
		Blanched	0.9612	0.00405	0.061467	0.002290
	70	Control	0.9716	0.00330	0.055026	0.002931
		Blanched	0.9801	0.00228	0.045751	0.003006
Page	50	Control	0.9952	0.00058	0.022551	0.005790
		Blanched	0.9830	0.00168	0.038321	0.009509
	60	Control	0.9934	0.00077	0.025864	0.006189
		Blanched	0.9910	0.00100	0.029575	0.007921
	70	Control	0.9964	0.00047	0.019697	0.003884
		Blanched	0.9978	0.00028	0.015308	0.000481
Modified Page	50	Control	0.9634	0.00437	0.061802	0.002880
		Blanched	0.9729	0.00269	0.048513	0.005866
	60	Control	0.9535	0.00540	0.068430	0.000133
		Blanched	0.9612	0.00436	0.614670	0.002283
	70	Control	0.9716	0.00363	0.055026	0.002947
		Blanched	0.9801	0.00251	0.045752	0.003216

Table 3: Continued

Model	Drying temperature (°C)	Pretreatment	r^2	χ^2	RMSE	MBE
Henderson and Pabis	50	Control	0.9726	0.00326	0.053423	0.012428
		Blanched	0.974	0.00259	0.047599	0.008755
	60	Control	0.9645	0.00414	0.059906	0.011169
		Blanched	0.9679	0.00361	0.055947	0.010732
	70	Control	0.9785	0.00275	0.047835	0.011631
		Blanched	0.9853	0.00186	0.039352	0.009799
Logarithmic	50	Control	0.9960	0.00054	0.020861	4.2E-060
		Blanched	0.9974	0.00028	0.015070	3.16E-05
	60	Control	0.9972	0.00035	0.016708	1.44E-05
		Blanched	0.9972	0.00034	0.016552	6.73E-05
	70	Control	0.9966	0.00041	0.019057	2.79E-05
		Blanched	0.9940	0.00023	0.025003	1.89E-05
Wang and Singh	50	Control	0.9973	0.15831	0.372185	0.276834
		Blanched	0.9935	0.11795	0.321261	0.009069
	60	Control	0.9975	0.05514	0.218612	0.162358
		Blanched	0.9979	0.07826	0.260425	0.190091
	70	Control	0.9976	0.19607	0.404212	0.296745
		Blanched	0.9948	0.37521	0.559172	0.409968
Two-term	50	Control	0.9726	0.00381	0.534230	0.012428
		Blanched	0.9739	0.00302	0.047602	0.008768
	60	Control	0.9645	0.00489	0.059906	0.011163
		Blanched	0.9679	0.00427	0.055947	0.010709
	70	Control	0.9785	0.00343	0.047836	0.011673
		Blanched	0.9853	0.00232	0.039352	0.009815
Two-term exponential	50	Control	0.9633	0.00437	0.061802	0.002802
		Blanched	0.9730	0.00270	0.048513	0.005810
	60	Control	0.9813	0.00225	0.044112	0.032954
		Blanched	0.9880	0.00135	0.034256	0.008526
	70	Control	0.9948	0.00065	0.023347	0.005379
		Blanched	0.9799	0.00256	0.046154	0.008401

Table 4: Moisture diffusivity values of tomato slices

Drying temperature (°C)	Pretreatment	D_{eff}, (µm^2 sec^{-1})	r^2
50	Control	1.68	0.9127
	Blanched	1.8	0.861
60	Control	1.91	0.846
	Blanched	2.18	0.8516
70	Control	2.73	0.919
	Blanched	2.84	0.9339

Moisture Diffusivity and Activation Energy

Values of D_{eff} with coefficient of correlation, r^2 are given in Table 4. Effective moisture diffusivity of tomato ranged from 1.68 to 2.84 µm sec^{-2}. These values are within the general range 0.1 to 10 µm sec^{-2} for drying of food materials (Maskan *et al*., 2002). The moisture diffusivity increased as drying air temperature was increased. Due to the influence of blanching on internal mass transfer of tomato during drying, blanched samples had higher moisture diffusivity values. Similar results of the influence of pretreatments on the moisture diffusivity during air drying have been found in apricots (Pala *et al*., 1996).

Activation energy of tomato slices was found to be 21.1 and 22.41 kJ^{-1} mol for untreated and blanched samples, respectively. The values were within the range (15-40 kJ^{-1} mol) of activation energy values reported by Rizvi (1986) for different foods. Activation energy of organically produced tomato slices was higher than soybean (Giner *et al*., 1994) and lower than red chillies (Kaleemullah *et al*., 2006) and green beans (Doymaz, 2005).

Conclusions

The effect of temperature and blanching on thin layer drying of organically grown tomato slices in a hot-air dryer was investigated. Increase in drying air temperature from 50 to 70°C decreased the drying time from 450 to 330 min. The entire drying process occurred in falling rate period. The logarithmic thin layer drying model showed better fit, than the other seven models evaluated, with high correlation coefficient and low χ^2, MBE and RMSE values. The moisture diffusivity of the tomato slices ranged from 1.68 to 2.84 μm sec^{-2} and activation energy of blanched and untreated samples were 22.42 and 21.1 kJ^{-1} mol, respectively.

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