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Thin layer hot air drying of bael *(Aegle marmelos)* fruit pulp

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Abstract

The bael *(Aegle marmelos)* is an important indigenous fruit and has various nutritional and therapeutic properties. Five air-drying temperatures (60, 65, 70, 75 and 80°C) and five thickness of pulp on the tray (2, 4, 6, 8 and 10 mm) were chosen to obtain the drying characteristics of bael fruit pulp. Moisture loss was recorded at every 5 min intervals during drying. The samples were also evaluated for variation in vitamin C and colour. The powder prepared from the pulp dried at 65°C with a drying thickness of 2 mm was found optimum with respect to drying time, colour and ascorbic acid content. Two term model gave the best results for describing the drying kinetics of bael fruit pulp. Temperature at 65°C can be considered as the limiting temperature for drying of bael pulp to observe minimum reasonable change in colour and ascorbic acid content. Loss of vitamins was also more with increase in temperature and thickness of layer.

Introduction

The bael *(Aegle marmelos)* is an important indigenous fruit, which is generally grown in Southeast Asia and has various nutritional and therapeutic properties. The pulp of fruit contains many functional and bioactive compounds such as carotenoids, phenolics, alkaloids, coumarins, flavonoids, terpenoids, and other antioxidants which may protect against chronic diseases. The medicinal properties of this plant have also been described in *'Charaka Samhita'* an early Sanskrit medicinal treatise. Bael fruit has demand for the native system of medicine such as the 'Ayurvedic'. The marmelosin content is found in the bael fruit which is known as panacea of stomach ailments (Singh and Nath, 2004). The ripened fruit is a tonic and is used for diseases like diarrhoea and dysentery. There are numerous references of its uses in traditional medicine (Arseculeratne *et al.*, 1981; Karunanayake *et al.*, 1984; Singh, 1986). Bael is usually processed into products like juice, preserves, refreshing beverages, powder, leather, squash, nectars, toffee, jam, syrup (Singh and Nath, 2004; Singh *et al.*, 2013).

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. The drying kinetics of food is a complex phenomenon and requires dependable models to predict drying behaviour. There are several studies describing the drying behaviour of various fruits, vegetables and medicinal plants such as apricots (Doymaz, 2004), mulberry (Doymaz, 2004a), aloe vera (Gulia, 2010), drumstick (Premi *et al.*, 2010), millet (Ojediran and Raji, 2010), carrot pomace (Kumar *et al.*, 2012), mango pulp (Wilson *et al.*, 2012), safou pulp (Massamba *et al.*,2012), okra (Ismail and Iba Idriss, 2013) and Arabica coffee (Muhidong and Rahman, 2013). Numbers of fruits, vegetables and medicinal plants are dried for their uses in the foods and medicines. The method adopted is mostly empirical in nature and requires systematic methodology for obtaining the good quality product. No systematic methodology is reported so far made for getting a dried product from bael fruit. Therefore, the present study focuses to investigate the drying behaviour of bael fruit pulp and to investigate a suitable drying

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model for describing the drying kinetics.

Materials and Methods

Materials

The bael fruits *(Aegle marmelos)* of Kaghzi variety, used in the drying experiments were procured from Krishi Vigyan Kendra, R.B.S. College, Bichpuri, Agra (India). The fruit pulp was extracted according to the method adopted by Roy and Singh (1979). The crude mass (pulp + seeds + fibre) was added with equal quantity of water, mixed and heated for 1 min at 80°C while maintaining the pH 4.3 with the help of citric acid solution. The mixture was passed through 20 mesh sieves to obtain pulp for drying purpose. Initial and final moisture contents of samples were estimated using the standard hot air oven method (AOAC, 1995). The ascorbic acid content of pulp was determined by the standard method (Ranganna, 1979).

Drying equipment

The hot air cabinet dryer (M/s Standard Instruments Corporation, Patiala, India), equipped with an electrical heater, fan and temperature indicators, was used for drying of bael fruit pulp. It consisted of trays (800×400×30 mm^3), temperature controller (0–300±1°C, dry bulb temperature) and a blower to provide air velocity of 1.5±0.2m/s.

Drying experiments

Before drying experiments, initial moisture content of the examples was determined. The initial moisture content of bael fruit pulp was 551.6% (db) and final moisture content of the finished product was about 11% (db). Five air-drying temperatures (60, 65, 70, 75 and 80°C) and five thickness of pulp on the tray (2, 4, 6, 8 and 10 mm) were chosen to obtain the drying characteristics of bael fruit pulp (Figure 1). After the dryer reached at steady-state conditions for the set points (for 1 h), the pulp was distributed uniformly into the tray in all five thicknesses. Moisture loss was recorded at every 5 min intervals during drying as per the method adopted by Wang *et al*. (2007) and Kumar *et al*. (2011, 2012). For measuring the weight of the sample during experimentation, the tray with sample was taken out of the drying chamber, weighed on the digital top pan balance and placed back into the chamber (within 15 s). The digital top pan balance was kept very close to the drying unit. Drying was continued until the moisture content of sample reached about 11% (db). The experiments were conducted in duplicate. The dried samples were cooled at normal room temperature (30±2°C) and packed in polyethylene bags (film thickness 90 μm) and sealed.

Colour measurement

The dried pulp flakes were ground in a laboratory grinder (Sujata, New Delhi, India) and passed through 80 mesh sieve to obtain fine powder of uniform particle size. The colour of powder was measured by Hunter colour measuring system (Hunter colour difference meter, Miniscan XE plus, Hunter Associates Laboratory Inc., Reston, VA). The colour was measured in terms of L^*, a^* and b^* values, where L^* is the lightness (0 = black, 100 = white), a^* for the red-purple (positive values) to the bluish-green (negative values) and b^* indicates the yellowness (positive values) and blueness (negative values).

Mathematical modeling of drying curves

The moisture ratio and drying rate of bael fruit pulp were calculated using the following equations (Premi *et al.*, 2010),

$$Moisture\ Ratio = \frac{M - M_f}{M_o - M_f} \quad \ldots(1)$$

$$Drying\ Rate = \frac{M_{t+dt} - M_t}{d_t} \quad \ldots(2)$$

Where M = moisture content at any given instant, % db, M_f =final moisture content, % db, M_o = initial moisture content, % db, M_t = moisture content at t, % db and M_{t+dt} =moisture content at t+dt, % db. The data were fitted with different mathematical models as given in Table 1.

The regression analysis was performed using the STATISTICA 10 (Statsoft India Pvt. Ltd., India) for selecting the best equation to explain the drying curve. Different drying models were compared according to their coefficients of determination (R^2), root mean square error (RMSE) and chi square (χ^2) to determine the best fit. These critical parameters were calculated as follows.

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{Exp,i} - MR_{Pre,i})^2}{(N - Z)} \quad \ldots(3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{Pre,i} - MR_{Exp,i})^2} \quad \ldots(4)$$

where, $MR_{Exp.i}$ is the i^{th} experimentally observed moisture ratio, $MR_{Pre.i}$ is the predicted moisture ratio, N is the number of observations and Z is the number of constants of each respective model. The model is said to be good if R^2 value is high, χ^2 and RMSE values are low.

Table 1. List of Models with references

S. No.	Model name	Model	References
1	Approximation of diffusion	MR = a exp(- kt) + (1 - a) exp(- k a t)	Yaldiz *et al.* (2001)
2	Henderson and Pabis	MR = a exp(- kt)	Henderson and Pabis (1961)
3	Logarithmic	MR = a exp(- kt) + c	Togrul and Pehlivan (2002)
4	Magee	MR = a+kt$^{1/2}$	Magee *et al.* (1983)
5	Midilli–Kucuk	MR = a exp(-kt^n) + bt	Midilli *et al.* (2002)
6	Newton	MR = exp(- kt)	Bruce (1985)
7	Page	MR = exp(- kt^n)	Page (1949)
8	Two Term	MR = a exp(- kt) + b exp(- gt)	Henderson (1961)
9	Verma	MR = a exp(-kt)+(1 – a) exp(-gt)	Verma *et al.* (1985)
10	Wang and Singh	MR = 1 + at + bt^2	Wang and Singh (1978)

Table 2. Variation of drying duration and maximum drying rates for drying of pulp at various temperatures and thickness

Temperature °C	Thickness of layer 2 mm	4 mm	6 mm	8 mm	10 mm
	Drying duration, min				
60	240	270	270	300	330
65	210	240	270	270	300
70	210	240	240	270	300
75	180	210	240	240	270
80	165	180	180	210	270
	Maximum drying rate, g water/ g dry matter/ min				
60	23.32	20.91	19.12	14.32	11.13
65	24.91	23.14	19.77	18.93	10.00
70	28.04	25.76	20.79	20.24	14.01
75	31.20	26.73	22.66	21.59	15.41
80	32.21	28.49	25.00	22.79	17.70

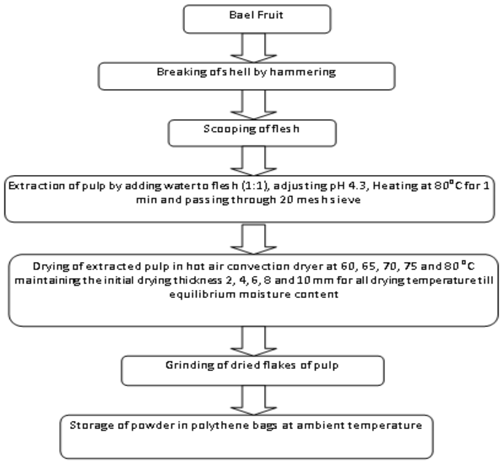

Figure 1. Flow chart of bael fruit pulp drying

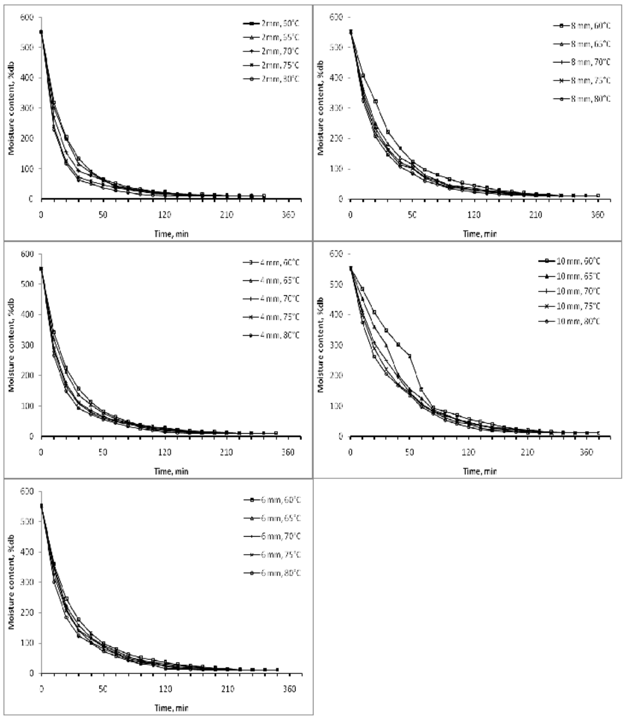

Figure 2. Thin layer drying curves of bael fruit pulp at various thickness and temperatures

Results and Discussion

Drying characteristics of bael fruit pulp

The moisture content versus drying time for various layer thicknesses of bael fruit pulp and at the selected temperatures is shown in Figure 2. Moisture loss of pulp as a function of drying time was very similar for all drying temperatures and drying thickness. The decrease in moisture content was faster in the starting of drying process, which is evident due to availability of high moisture initially. Moisture depletion per hour was higher at initial stages and then started to decrease with drying time. These results are in good agreement with the earlier studies Meisami-asl and Rafiee (2009) for apple drying and Kumar *et al.* (2011) for carrot pomace drying. It can further be observed that the moisture content decreased at a faster rate for the samples having lesser thickness, which may be due to increase in thickness of inner layers of pulp resulting in lower moisture removal. However, a faster decrease in moisture content was observed at 60°C for 10 mm thickness after 60 minute, which may be due to rupture of upper crust of pulp formed due to surface hardening at lower temperature and more thick drying layer. This indicates the improper drying of bael fruit pulp at this set of conditions. This phenomenon was not occurred at raised temperature or less thickness of the bael fruit pulp.

It can be noted from Figure 2 and Table 2 that the drying times to reach the final moisture content for the fresh bael pulp sample were 240 - 165; 270 - 180; 270 - 180; 300 - 210; 330 - 270 at temperatures of 60 - 80°C for various thickness of 2, 4, 6, 8 and 10 mm respectively. Obviously, within a certain temperature range (60–80°C), increasing drying temperature speeds up the drying process, thus shortens the drying time. Similar findings have been reported for fruit and vegetable products drying (Vergara *et*

Table 3. ANOVA for Variation of drying duration and maximum drying rates for drying of pulp at various temperatures and thickness

Source of Variation	SS	df	MS	F	P-value	F crit
Drying duration						
Rows	19044	4	4761	46	1.403E-08	3.00
Columns	24084	4	6021	58.17	2.49E-09	3.00
Error	1656	16	103.5			
Total	44784	24				
Maximum drying rate						
Rows	183.6	4	45.90	44.22	1.9E-08	3.00
Columns	595.31	4	148.83	143.39	2.6E-12	3.00
Error	16.61	16	1.04			
Total	795.52	24				

Table 4. Effect of temperature and thickness on the color values and Ascorbic acid of bael fruit powder

Parameters	Temp. (^{0}C)	Drying Thickness			
		2 mm	4 mm	6 mm	8 mm
Colour - L*	60	61.23±0.45	59.9±0.63	56.86±0.31	47.98±0.34
	65	57.1±0.61	52.73±0.87	49.36±0.97	47.03±0.42
	70	46.76±0.32	43.53±0.26	42.63±0.67	41.7±0.38
	75	46.59±0.73	43.51±0.44	42.09±0.73	41.51±0.24
	80	43.52±0.17	43.18±0.29	41.55±0.87	38.44±0.27
Colour - a*	60	10.88±0.73	11.6±0.25	11.73±0.33	12.37±0.14
	65	14.66±0.32	17.07±0.83	17.45±0.41	18.13±0.37
	70	14.49±0.23	17.28±0.32	17.7±0.22	18.24±0.41
	75	16.23±0.56	17.86±0.37	17.96±0.43	18.25±0.67
	80	16.63±0.62	17.93±0.49	18.51±0.19	19.01±0.37
Colour - b*	60	39.54±0.11	39.39±0.64	38.66±0.33	37.98±0.21
	65	38.78±0.23	37.9±0.53	37.57±0.45	37.3±0.67
	70	36.97±0.33	36.43±0.12	36.02±0.24	34.11±0.42
	75	35.54±0.53	35.09±0.08	34.02±0.22	33.36±0.34
	80	33.94±0.27	33.59±0.42	31.72±0.13	30.96±0.11
Ascorbic acid content (mg/100g db)	60	12.3±0.31	11.8±0.31	9.8±0.25	9.1±0.49
	65	11.6±0.48	10.8±0.42	9.6±0.48	8.9±0.11
	70	11.2±0.32	10.4±0.33	8.8±0.54	8.2±0.23
	75	10.3±0.39	9.6±0.11	8.3±0.33	7.8±0.61
	80	8.8±0.42	8.1±0.41	7.2±0.23	6.8±0.32

al., 1997; Fenton and Kennedy, 1998; Ramaswamy, 2002; Wang *et al*., 2007). The drying time increased with the increase in thickness of drying layer, which is evident due to less exposed area available for evaporation per unit mass of pulp. F values (Table 3) for layer thickness and temperatures indicates that the increase in drying time with thickness and decrease in drying time with increase in temperature are significant.

The moisture ratio decreased continuously as the progress of drying process (Figure 3). Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in air heat supply rate to the pulp and the acceleration of moisture migration (Demir *et al.,* 2004). It took only about 10 to 40 minutes to remove first half moisture, remaining time was elapsed to remove the residual moisture due to slower diffusion. Similar comparatively large duration in drying the residual moisture for carrot pomace drying was also reported by Kumar *et al*. (2012).

It can be observed from Figure 4 that drying rate decreased with the moisture content, which is evident due to decrease in free moisture available for evaporation. Constant rate period was absent and the drying process of bael fruit pulp took place in falling rate period. Drying rate was very similar for all drying temperatures and drying thickness. The drying rate was faster in the starting, which is evident due to availability of free moisture initially. It can be observed from Table 2 that the drying rate was decreased with the increase in thickness and increased with the increase in temperature.

Table 5. ANOVA for variation in colour and ascorbic acid due to effect of temperature and thickness

Source of Variation	SS	df	MS	F	P-value	F crit
Colour - L*						
Rows	650.24	4	162.55	38.74	9.06E-07	3.25
Columns	159.87	3	53.29	12.69	0.00049	3.49
Error	50.35	12	4.19			
Total	860.46	19				
Colour - a*						
Rows	107.49	4	26.87	122.52	1.28E-09	3.26
Columns	19.36	3	6.46	29.43	8.15E-06	3.49
Error	2.63	12	0.22			
Total	129.49	19				
Colour - b*						
Rows	104.21	4	26.05	137.73	6.45E-10	3.26
Columns	14.35	3	4.79	25.30	1.78E-05	3.49
Error	2.27	12	0.19			
Total	120.84	19				
Ascorbic acid						
Rows	22.03	4	5.51	80.49	1.46E-08	3.26
Columns	22.87	3	7.62	111.44	5E-09	3.49
Error	0.82	12	0.07			
Total	45.72	19				

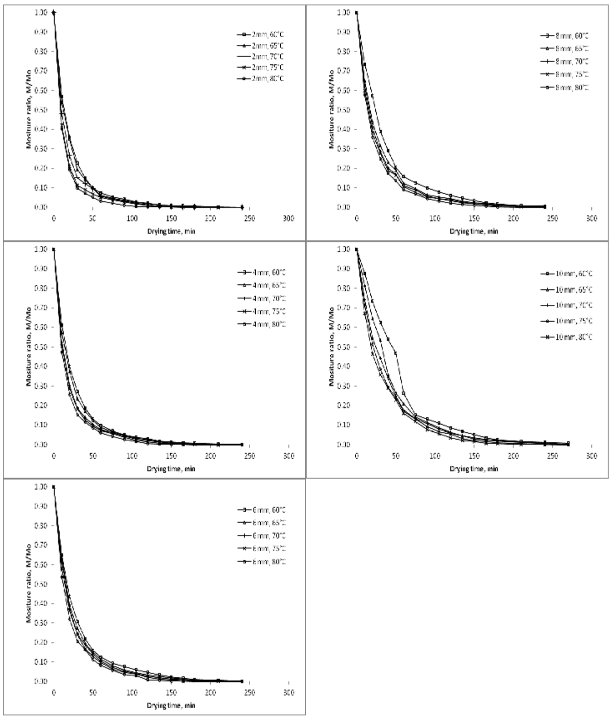

Figure 3. Moisture ratio variation of bael fruit pulp with various thickness and temperatures

F values for layer thickness and drying temperatures (Table 3) indicates the variation in drying rates was significant (P<0.001). Experimental results showed that drying air temperature is effective parameter for the drying of bael fruit pulp. It can be seen that at higher moisture content, the increase in temperature has more considerable effect on the drying rates as compared to lower temperatures, which is almost negligible towards the end. It was further observed that the drying rate or moisture loss was faster at the beginning than that at the end. The reduction in the drying rate at the end of drying may be due to the reduction in moisture content as drying advances. Thus, a higher drying air temperature produced a higher drying rate and consequently the moisture content decreased (Lahsasni *et al*., 2003).

Effect of drying temperature and thickness on the color

Colour is an important quality parameter in determining the powder quality. The dried samples were ground to powder form and were evaluated for color. It was observed from Table 4 that the bael pulp dried at 60°C was lighter in colour and L^*value decreased with an increase in temperature and thickness indicating the darkening of the powder. Colour a^* value which indicates the reddishness, increased with increasing temperature and thickness, which may be due to the increase in non-enzymatic browning to pulp at higher temperatures or long exposure to drying operation. Colour b^* value which indicates the yellowness, was decreased during the drying with increase in temperature, which may be due to degradation of vitamins and pigments with heat treatment. F values for colour L^*, a^* and b^* for change in thickness and change in temperature (Table 5), indicates that change in colour due to change in process parameters is significant (P<0.01). The increase in drying thickness adversely affected the

Table 6. Model coefficients and statistical parameters for recommended Two Term model at various temperatures and drying thickness

Temp. (^{0}C)	Thickness (mm)	Coefficients				Coefficient of determination (R^2)	Chi-square (χ^2)	RSME
		a	k	b	g			
60	2	0.7737	3.2604	0.8564	0.0426	0.9976	1.30E-04	0.0103
	4	0.2256	0.0182	0.7473	0.0565	0.9998	6.50E-06	0.0023
	6	0.2963	0.0166	0.7133	0.0588	0.9997	1.50E-05	0.0035
	8	0.2261	0.0133	0.8324	0.0411	0.9984	1.60E-04	0.0113
	10	0.5663	0.0214	0.5666	0.0214	0.9927	1.20E-03	0.0322
65	2	1.4688	0.0441	-0.6381	0.0441	0.9971	1.54E-04	0.0109
	4	0.2383	0.0193	0.7013	0.0621	0.9997	1.49E-05	0.0034
	6	0.3952	0.0211	0.7285	0.0843	0.9999	3.71E-06	0.0017
	8	0.6345	0.0576	0.3504	0.0185	0.9996	3.27E-05	0.0051
	10	0.0565	0.0081	1.0366	0.0285	0.9981	2.59E-04	0.0144
70	2	0.7854	0.1194	0.3185	0.0268	0.9992	3.32E-05	0.0050
	4	0.2832	0.0219	0.7502	0.0928	0.9998	1.08E-05	0.0029
	6	0.4233	0.0232	0.7478	0.0984	0.9998	1.32E-05	0.0032
	8	0.6429	0.0683	0.3674	0.0200	0.9997	2.33E-05	0.0043
	10	0.2147	0.0141	0.7717	0.0333	0.9993	7.63E-05	0.0078
75	2	0.2060	0.0240	0.8688	0.1202	0.9994	1.91E-05	0.0038
	4	0.7248	0.0991	0.3013	0.0242	0.9998	8.91E-06	0.0026
	6	0.6259	0.0866	0.4068	0.0247	0.9999	7.33E-06	0.0024
	8	0.4355	0.0226	0.5781	0.0829	0.9994	3.89E-05	0.0055
	10	-0.6225	0.0270	1.5312	0.0270	0.9985	0.00015	0.0108
80	2	0.2485	0.0346	0.7926	0.1244	0.9994	1.74E-05	0.0036
	4	0.3442	0.0291	0.7695	0.1270	0.9996	1.77E-05	0.0036
	6	0.5113	0.0300	0.7082	0.1494	0.9996	2.39E-05	0.0042
	8	0.4741	0.0265	0.5586	0.0959	0.9998	1.01E-05	0.0028
	10	575.6004	0.8983	0.7725	0.0252	0.9997	2.59E-05	0.0045

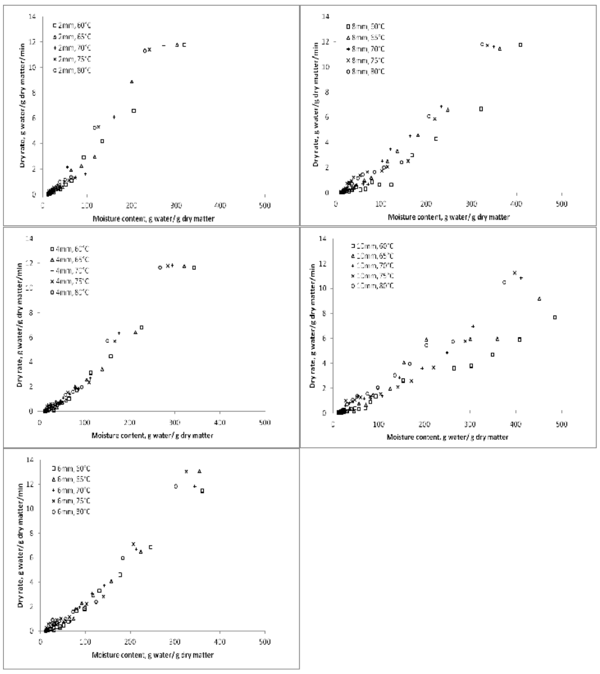
Figure 4. Variation of drying rate with moisture content

colour. This may be due to longer residence time of sample in the drier. A rapid change can be observed in colour when the temperature is increased above 65^{0}C. Hence 65^{0}C can be considered as the limiting temperature for drying of bael pulp to observe minimum reasonable change in colour.

Effect of drying temperature and thickness on ascorbic acid content

The ascorbic acid in pulp was 55 mg/100 g (db) initially. The ascorbic acid present in the bael pulp was reduced during drying. The increase in drying temperature adversely affected the ascorbic acid content. The ascorbic acid content of dried samples, dried with different bed thicknesses (2 to 8 mm) showed a variation between 6.8 to 12.3 mg / 100g db (Table 4). The loss of ascorbic acid increased with an increase in drying thickness, which may be due to the destructive effect of the prolonged thermal treatment, which caused oxidation of the ascorbic acid. The F values for change in ascorbic acid due to variation in temperature and thickness indicates the variation in ascorbic acid is significant ($p<0.001$). The similar findings were given by Rajkumar *et al.* (2007) for mango pulp and Kandasamy *et al.* (2012) for papaya pulp.

Mathematical models for fitting of drying curves

The moisture ratio data of bael fruit pulp dried at different temperatures were fitted into the drying models (Table 1). It can be observed from Figure 5 that the R^2 values for Approximation of diffusion (S. No.1), Handerson and Pabis (S. No.2), Logarithmic (S. No.3), Newton (S. No.6), Page (S. No. 7) and Two term (S. No. 8) mathematical models were greater than 0.9980 and χ^2 and RMSE values were lower 0.0002 and 0.1434 respectively, indicating the fitness of the models in predicting the data. The

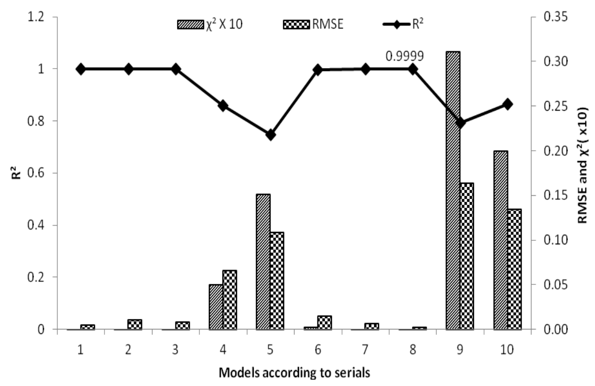

Figure 5. Statistical parameters of modeling

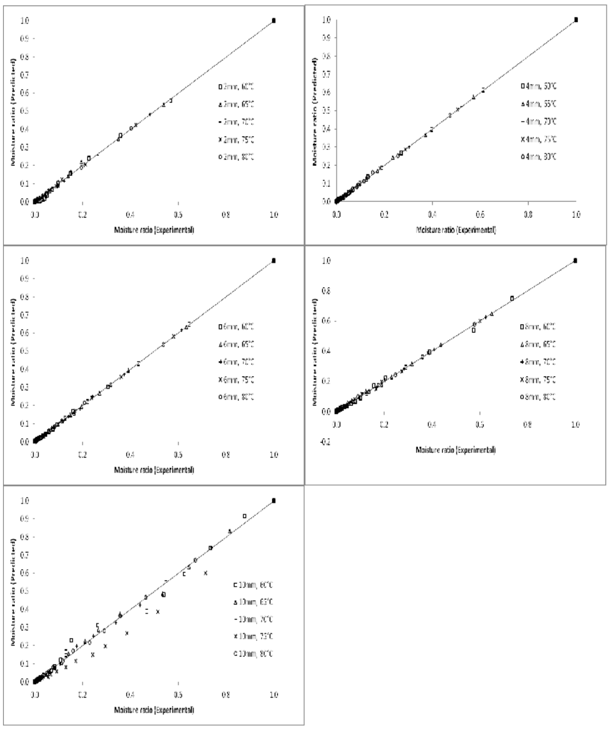

Figure 6. Experimental and predicted values of moisture ratio using Two Term model

results showed that highest values of R^2 and lowest values of χ^2 and RMSE values of two term model were obtained at all the temperatures. The overall R^2, χ^2 and RMSE at different temperatures and thickness were 0.9999, 3.71E-06 and 0.0017 respectively. Therefore, this model can be considered to represent the drying behavior of bael fruit pulp in a convective type dryer. Abbaszadeh *et al.* (2011) and Chayjan *et al*. (2012) have reported the suitability of same model for thin layer drying of *Lasagnas angustifolia* L. and pistachio, respectively. The drying constants (k) and (b) and coefficients (a) and (n), also statistical parameters R^2, chi-square and RMSE for Two term model are shown in Table 6.

The variation of the Two Term model was established by comparing the experimental data with predicted values for each drying condition. The plotted responses in Figure 6 demonstrated that the data points followed a straight line at 45° angle signifying the suitability of the model in describing the drying of the bael fruit pulp.

Conclusions

Bael fruit pulp was dried at 60, 65, 70, 75 and 80°C temperature with 2,4,6,8 and 10 mm drying thickness. The drying rate decreased continuously throughout the drying period. Constant rate period was absent and the drying process of bael fruit pulp took place in falling rate period. Drying time decreased considerably with increased temperature and decrease in thickness. Two term model was the best among the selected models for describing the drying behaviour of bael fruit pulp. The decrease in ascorbic acid content, L^* and b^* values and increase in a^* value was observed with increase in drying temperature and thickness of layers. Temperature 65°C was found limiting temperature with respect to the colour and ascorbic acid content. Hence the pulp dried at 65°C and 2 mm drying thickness was found optimum with respect drying time, colour and ascorbic acid content of bael pulp powder.

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