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Mathematical Modelling of Thin Layer Drying Kinetics of Amla-Beet Root Shreds

Mandali Pooja Rasagna* and S.K. Jain

Department of Processing and Food Engineering, College of Technology and Engineering, Udaipur 313 001, India

**Corresponding author*

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Drying kinetics of amla- beet root shreds in tray dryer was studied at 55, 65 and 75°C air temperatures. Drying of shreds occurred completely in falling rate period. Four thin layer drying models were fitted to the experimental moisture ratio data. Among the mathematical models investigated, the logarithmic model satisfactorily described the drying behaviour of shreds with high r^2 values.

Introduction

Indian gooseberry (*Emblica officinalis Gaertn*.) also known as aonla is a low cost important fruit valued for its nutritional and medicinal properties. It is one of the richest sources of ascorbic acid (500–1,500 mg/100 g) used as a strong rejuvenator in Indian pharmacopoea (Pathak and Ram, 2007) and is very popular for its medicinal properties as mentioned both in ayurvedic and unani system of medicines in India. It is valued as an anti-ascorbic, acidic, cooling laxative and diuretic (Singh *et al.*, 1993). Beetroot (*Beta vulgaris L*.) commonly known as 'chukander', is mainly cultivated in India for its juice and vegetable value. Beetroot is a rich source of potent antioxidants and nutrients, including magnesium, sodium, potassium and vitamin C, and betaine. They are loaded with vitamins A, B_1, B_2, B_6 and C. They are also an excellent source of calcium, magnesium, copper, phosphorus, sodium and iron.

Traditionally fruits and vegetables are dried in open sunlight, which is weather dependable and also prone to microbial and other contamination (Mathioulakis *et al.*, 1998). To achieve consistent quality dried product industrial dryers should be used. Industrial dryers are rapid and provide uniform, hygienic dried product (Abdelhaq and Labuza, 1987; Doymaz and Pala, 2002; Karathanos and Belessiotis, 1997).

The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimizing the drying parameters. Thin layer drying equations were used for drying time prediction for generalization of drying curves (Karathanos and Belessiotis, 1999). Extensive research in drying behaviour of pre-treated fruits was reported (Doymaz, 2004a, 2004b; Mahmutoglu *et al.*, 1995; Saravacos *et al.*, 1988; Verma and Gupta, 2004). But, no detailed studies were found in literature on drying kinetics of amla- beet root shreds. The objective of this study were (i) to study the drying kinetics of amla- beet root in a tray dryer and (ii) to evaluate a suitable thin layer drying model.

Materials and Methods

Experiment

Fresh matured Amla and beet root will be collected from local market, Udaipur. Fresh fruit samples will be washed and cut into small segments by using a manual shredder. Five different combinations of amla- beet root shreds were made on weight basis [C_1=(400, 0); C_2=(300,100); C_3 =(200,200); C_4 = (100, 0); C_5 = (0, 100)].Each combination contained 400 g shreds. Each combination was blanched in one litre boiling water for 3min and dipped immediately in normal water for 3 min to prevent excess cooking, then the blanched product was kept in strainer. Three percent (12 g) of black salt and 10 percent (40 ml) ginger juice was given to each combination and kept for 12 h for uniform absorption (Prajapathi *et al., 2010*). The product was conditioned to remove surface moisture. Shreds were dried in tray dryer at three different temperatures (55 (T_1), 65 (T_2), 75 (T_3) ^oC) in trays. The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. Amla- beet root shreds were uniformly spread in rectangular aluminium trays and kept in the tray dryer for drying. Moisture loss was recorded at 30 min interval by a digital balance of 0.01 g accuracy. The drying was continued till there is no large variation in the moisture loss. Experiments were conducted in triplicate.

Drying models

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

$$\text{Moisture ratio} = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

To select a suitable model for describing the drying process of amla- beet root shreds, drying curves were fitted with four thin layer drying equations. The moisture ratio models that are evaluated are presented in Table 1.The non-linear regression analysis was analysed using SPSS (Statistical Package for Social Science) 13.2 software package. 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 mean bias error, MBE and root mean square error, RMSE. For quality fit, r^2 value should be higher and MBE and RMSE values should be lower (Demir *et al.*, 2004; Erenturk et al., 2004; Pangavhane *et al.*, 1999; Sarsavadia *et al.*, 1999; Togrul and Pehlivan, 2002).

Results and Discussion

Drying characteristics

The time taken for drying of amla- beet root shreds at different temperature is given in Table 2. The final moisture content of shreds ranged from 6% to 11% (d.b.). It is evident that the drying air temperature has an important effect on drying. When the temperature was increased, the drying time reduced. 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 ln(MR) versus drying time for the samples dried at different temperature with different percentage of amla and beet root shreds are shown in Figs. 1–5. The moisture ratio decreased continuously with drying time. An increase of drying rate was observed with the increase in temperature. Drying of amla-beet root shreds occurred in falling rate period and due to quick removal of moisture, no constant rate period was observed. Similar observations have been reported for the drying of red chillies (Chandy *et al.*, 1992), onion slices (Rapusas and Driscoll, 1995) and apricots (Doymaz, 2004a). The drying in falling rate period shows that, internal mass transfer has occurred by diffusion.

Fig.1 Variation in ln(MR) with time for various drying airtemperatures for C_1

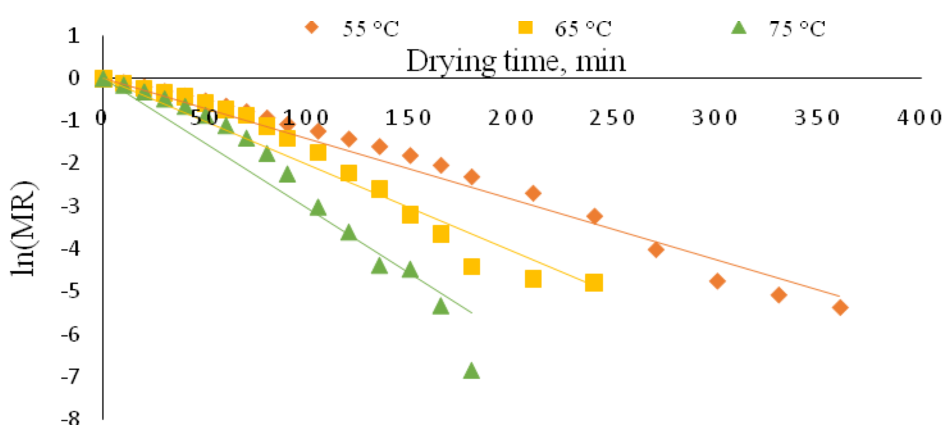

Fig.2 Variation in ln(MR) with time for various drying airtemperatures for C_2

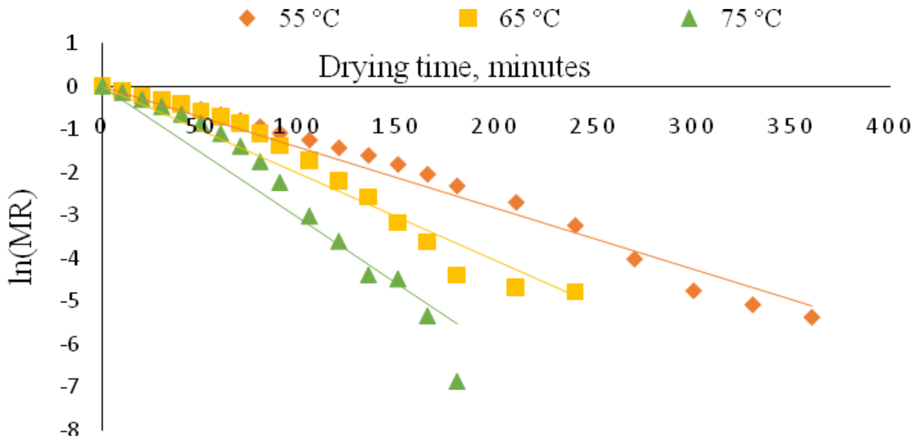

Fig.3 Variation in ln(MR) with time for various drying airtemperatures forC_3

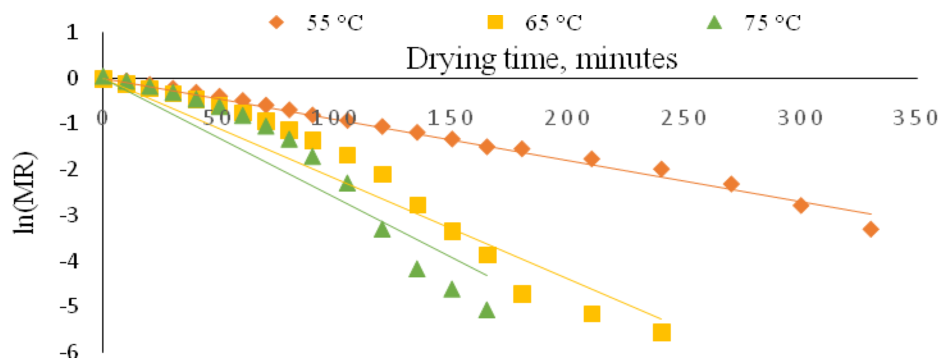

Fig.4 Variation in ln(MR) with time for various drying airtemperatures for C_4

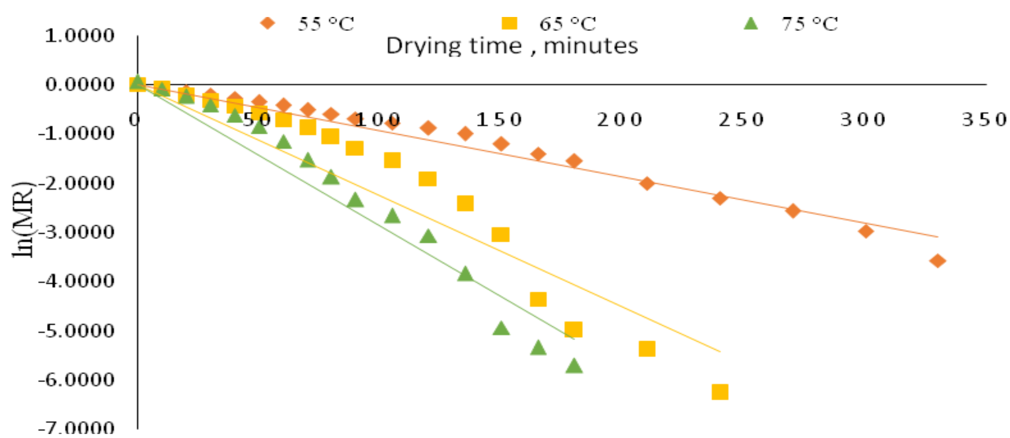

Fig.5 Variation in ln(MR) with time for various drying airtemperatures for C_5

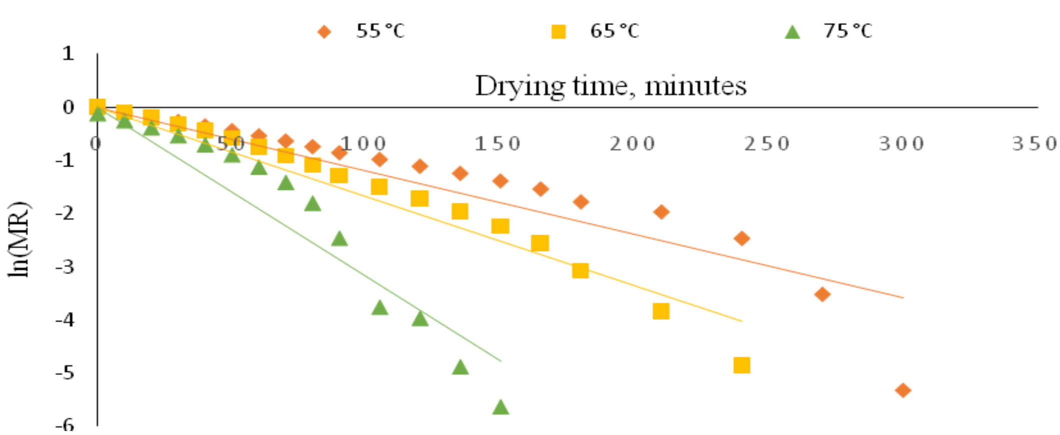

Table.1 Mathematical Models Used in Investigation

Equation	Name	References
MR = exp(kt)	Newton	Liu and Bakker-Arkema (1997) and O'Callaghan *et al.*, (1971)
MR = exp(kt^n)	Page	Zhang and Litchfield (1991)
MR = aexp(kt)	Henderson and Pabis	Henderson and Pabis (1961) and Chhinnman (1984)
MR = aexp(kt) + c	Logarithmic	Yaldiz *et al.*, (2001)

Table.2 Drying time for amla- beet root shreds

Sample	Drying time (min) at different temperatures		
	55° C	65° C	75° C
C_1	360	240	180
C_2	360	300	180
C_3	360	270	180
C_4	360	270	180
C_5	360	270	180

Table.3 Results on thin layer drying of C_1at different temperatures

Name of Model	Air Temp (°C)	Drying constant				Statistical parameters		
		K	**n**	**A**	**c**	**MBE**	**R^2**	**RMSE**
Newton model	55	0.012	-	-	-	0.0021	0.995	0.0268
	65	0.013	-	-	-	0.0033	0.995	0.0288
	75	0.019	-	-	-	0.0052	0.997	0.02156
Logarithmic	55	0.011	-	1.101	-0.072	0.0012	0.998	0.0161
	65	0.011	-	1.100	-0.085	0.0001	0.999	0.0103
	75	0.016	-	1.029	-0.048	0.0004	0.998	0.01545
Page	55	0.984	0.000001	-	-	0.00000	0.969	0.20538
	65	1.086	0.000001	-	-	0.00044	0.928	0.26738
	75	1.268	0.000001	-	-	0.00084	0.901	0.23542
Henderson and Pabis model	55	0.012	-	1.048	-	0.00470	0.996	0.02376
	65	0.014	-	1.039	-	0.00699	0.996	0.02531
	75	0.019	-	0.997	-	0.00500	0.997	0.07074

Table.4 Results on thin layer drying of C_2 at different temperatures

Name of Model	Air Temp (°C)	Drying constant				Statistical parameters		
		k	**N**	**A**	**C**	**SSE**	**R^2**	**RMSE**
Newton model	55	0.0116	-	-	-	0.0019	0.9982	0.01547
	65	0.0142	-	-	-	0.0034	0.9742	0.04231
	75	0.0196	-	-	-	0.0066	0.9883	0.04788
Logarithmic	55	0.0110	-	1.0454	-0.03	0.0004	0.9993	0.01118
	65	0.0130	-	1.1187	-0.06	0.0006	0.9991	0.02841
	75	0.0166	-	1.1324	-0.09	0.0016	0.9997	0.02991
Page	55	0.0070	1.11	-	-	0.0015	0.9997	0.00581
	65	0.0028	1.37	-	-	0.0054	0.9977	0.02199
	75	1.2933	0.000001	-	-	0.0000	0.9417	0.27290
Henderson and Pabis model	55	0.0119	-	1.0251	-	0.0046	0.9986	0.0162
	65	0.0152	-	1.0702	-	0.0116	0.9896	0.04708
	75	0.0172	-	1.095	-	0.012	0.985	0.0564

Table.5 Results on thin layer drying of C_3 at different temperatures

Name of Model	Air Temp (°C)	Drying constant				Statistical parameters		
		k	N	A	c	SSE	R^2	RMSE
Newton model	55	0.0087	-	-	-	0.0018	0.9981	0.01518
	65	0.0146	-	-	-	0.0045	0.988	0.0374
	75	0.0079	-	-	-	0.0010	0.974	0.07823
Logarithmic	55	0.0087	-	1.0397	-0.01	0.0001	0.9993	0.0063
	65	0.0126	-	1.1152	-0.08	0.0005	0.9991	0.0049
	75	0.0122	-	1.2869	-0.20	0.0014	0.9994	0.0063
Page	55	0.9270	0.000001	-	-	0.0009	0.9992	0.00997
	65	1.2041	0.000001	-	-	0.0009	0.9725	0.28396
	75	1.0886	0.000001	-	-	0.0023	0.9147	0.30540
Henderson and Pabis model	55	0.0090	-	1.0296	-	0.0011	0.9992	0.01165
	65	0.0154	-	1.0508	-	0.0121	0.9904	0.04452
	75	0.0178	-	1.1301	-	0.0160	0.9838	0.06251

Table.6 Results on thin layer drying of C_4 at different temperatures

Name of Model	Air Temp (°C)	Drying constant				Statistical parameters		
		k	N	A	C	SSE	R^2	RMSE
Newton model	55	0.0079	-	-	-	0.0007	0.9941	0.03362
	65	0.0137	-	-	-	0.0043	0.9866	0.05419
	75	0.0190	-	-	-	0.0007	0.9811	0.06716
Logarithmic	55	0.0066	-	1.1340	-0.11	0.0001	0.9991	0.01111
	65	0.0120	-	1.1571	-0.10	0.0001	0.9996	0.03095
	75	0.0179	-	1.2036	-0.08	0.0001	0.9995	0.02468
Page	55	0.8667	0.000001	-	-	0.0001	0.988	0.24226
	65	1.1460	0.000001	-	-	0.0004	0.9672	0.23013
	75	1.2516	0.000001	-	-	0.0041	0.9411	0.29259
Henderson and Pabis model	55	0.0083	-	1.0476	-	0.0064	0.9959	0.02818
	65	0.0149	-	1.0843	-	0.0126	0.9905	0.04557
	75	0.0216	-	1.1430	-	0.0127	0.9910	0.04641

Table.7 Results on thin layer drying of C_5 at different temperatures

Name of Model	Air Temp (°C)	Drying constant				Statistical parameters		
		K	N	a	C	SSE	R^2	RMSE
Newton model	55	0.0081	-	-	-	0.00266	0.9946	0.03267
	65	0.0133	-	-	-	0.00089	0.9942	0.02663
	75	0.0169	-	-	-	0.00628	0.9811	0.06449
Logarithmic	55	0.0075	-	1.1185	-0.07	0.00000	0.9994	0.00905
	65	0.0123	-	1.1043	-0.06	0.0027	0.9991	0.02119
	75	0.0128	-	1.2176	-0.17	0.0000	0.9994	0.03475
Page	55	0.8814	0.000001	-	-	0.02138	0.9084	0.07945
	65	1.1088	0.000001	-	-	0.00032	0.9760	0.27186
	75	1.1551	0.000001	-	-	0.00002	0.9465	0.29001
Henderson and Pabis model	55	0.0088	-	1.0676	-	0.00471	0.9979	0.02043
	65	0.0142	-	1.0610	-	0.0069	0.9964	0.02659
	75	0.0182	-	1.0824	-	0.01517	0.9851	0.05742

Models

The moisture ratio data of shreds dried at different temperatures were fitted into the thin layer drying models (Table 1). The coefficient of correlation and results of statistical analyses are listed in Tables 3-7.In all cases, the r^2 values for the mathematical models were greater than 0.90, indicating a good fit. The results show that highest values of r^2 and lowest values of MBE and RMSE were obtained with the logarithmic model. Thus the logarithmic model may be assumed to represent the thin layer drying behaviour of amla- beet root shreds in tray dryer. Similar findings were reported for hot air drying of apricots (Doymaz, 2004a; Togrul and Pehlivan, 2002) and rosehip (Erenturk *et al.*, 2004).

From this study on drying of amla- beet root shreds in a tray dryer, the following conclusions were drawn:

Increase in drying air temperature decreased the drying time.

Logarithmic thin layer drying equation represented the thin layer drying behaviour of amla- beet root shreds.

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