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Drying kinetics and mathematical modeling of beetroot

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Abstract
An attempt has been made to study the drying behavior of beetroot slices using cabinet dryer. The beetroot slices were dried at 50, 55, 60, 65 and 70 + 1 °C for 660, 630, 420, 400 and 390 min respectively. There was 36.36 per cent reduction in drying time as compared to 50 and 60°C temperature while it was 40.90 per cent at 60 to 70 °C temperature. The drying rate decreased with increase in drying time. The drying occurred mostly in falling rate period. The drying rates were as high as 0.9 at 65 ºC and as low as 0.1 at 55 ºC.
The drying curves were fitted by means of four different moisture ratio mathematical models that are widely used in most food and biological materials; namely, Henderson and Pabis, Logarithmic, Page and Modified Page. The best model describing the drying process was selected based on the low RMSE, χ^2, high R^2 and adjusted R^2. The R^2 and adjusted R^2 values for the models were greater than 0.90, indicating a good fit. The R^2 and adjusted R^2 values for Logarithmic model were varied between 0.932 and 0.963, 0.926 and 0.960 respectively, χ^2 values between 0.07 and 0.11, and *RMSE* values between 0.151 and 0.208. The Logarithmic model was found to be a better model compared to other for describing the drying characteristics of beetroot at all temperatures.

Keywords: Beetroot, drying, drying curve, drying rate, mathematical models

1. Introduction
Beetroot (*Beta vulgaris* L.) belonging to the *Chenopodiaceae* family is indigenous to Asia and Europe. Beetroots are rich in carbohydrates, protein, fiber, minerals like iron potassium, magnesium, copper, calcium and potent antioxidants and betanin. Specific anti-carcinogens are bound to the red coloring matter, which supposedly helps to fight against cancer. Betanin is one of the approved food additives as a food colorant (E 162) and antioxidant.
Beetroot predominately contains pigments called betalains, a class of betalamic acid derivatives which are composed of betacyanins and betaxanthins (Pitalua *et al.*, 2010) [29]. The betalain and phenolic composition of red beetroot has been studied in detail by Kujala *et al.* (2000) [17] and Kujala *et al.* (2002) [18].
Beetroots are rich in valuable active compounds such as carotenoids (Dias *et al.*, 2009) [6], glycine betaine (de Zwart *et al.*, 2003) [4], saponins (Atamanova *et al.*, 2005) [2], betacyanines (Patkai *et al.* 1997) [27], folates (Jastrebova *et al.*, 2003) [12], betanin, polyphenols and flavonoids (Vali *et al*., 2007) [34]. Therefore, beetroot ingestion can be considered a factor in cancer prevention (Kapadia *et al.*1996) [14].
Consumption of red beet having antioxidants can contribute to protection from age related diseases. Beetroot is one of the most potent vegetables with respect to antioxidant activity (Vinson *et al.*, 1998, Zitnanova *et al.*, 2006 and Georgiev *et al.*, 2010) [35] [38] [10]. Betacyanins are a group of compounds exhibiting antioxidant and radical-scavenging activities (Escribano *et al.*, 1998 and Pedreno and Escribano, 2000) [7] [28]. They also inhibit cervical ovarian and bladder cancer cells in vitro (Zou *et al.*, 2005) [39].
Betalains and other phenolic compounds present in red beet decreases oxidative damage of lipids and improves antioxidant status in humans. Antioxidant activity in red beet is associated with involvement of antioxidants in the scavenging of free radicals and consequently in the prevention of diseases like cancer and cardiovascular diseases (Delgado-Vargas *et al.*, 2000) [5].
Fresh beetroots are exposed to spoilage due to their high moisture content. One of the preservation methods ensuring microbial safety of biological products is drying (Mathlouthi, 2001) [23]. Dried beetroots can be consumed directly in the form of chips as a substitute of traditional snacks, that are rich in trans fatty acids (Aro *et al.*, 1998) [1], or after easy

preparation as a component of instant food (Krejčová *et al*., 2007) [16]. Decreasing the moisture content of fresh foods to make them less perishable is a simple way to preserve these foods.

Convective drying in hot air is still the most popular method applied to reduce the moisture content of fruits and vegetables (Lewicki, 2006) [20], including beetroots (Kamin´ ski *et al*., 2004 and Shynkaryk *et al*., 2008) [13] [30]. However, this method has several disadvantages and limitations; for instance, it requires relatively long time and high temperatures, which causes degradation of important nutritional substances (Marfil *et al*., 2008) [21] as well as color alteration (Chua *et al*., 2001) [3]. It also causes shrinkage due to tissue collapse caused by volume reduction due to the loss of moisture as well as the presence of internal forces (Mayor and Sereno, 2004) [24].

Drying increases, the storage stability of fruits and vegetables making them available throughout the year.

2. Materials and Methods

2.1 Raw materials and sample preparation

Fresh and well matured beetroot were obtained from the local market of Rahuri, Dist. Ahmednagar. The beetroots were cleaned, washed, blanched (3-5 min at 80-90 °C), peeled and cut into thin slices (3-5mm) using sharp knife.

The beetroot slices were spread in a single layer on a tray and dried at 50, 55, 60, 65 and 70 + 1°C in a hot air cabinet dryer. The loss in weight was determined quickly after cooling using a laboratory weighing scale placed near the dryer. Readings were taken at a time interval of every 30 min till a constant weight was observed. The exact value for the respective temperature was assumed as the equilibrium moisture content in subsequent computations. Independent drying experiments were performed at various temperatures (50 to 70ºC).

2.2 Mathematical modeling

The experimental drying data of beetroot at different drying temperatures were fitted into four commonly used thin-layer drying models (Table 1).

Table 1: Drying models

Model No.	Name	Model Equation	References
1	Page	$MR = \exp(-kt^n)$	Jangam *et al*. (2008) [11]
2	Modified Page	$MR = \exp[-(kt)^n]$	Midilli *et al*. (2002) [25]
3	Henderson and Pabis	$MR = a\exp(-kt)$	Figiel (2010) [9]
4	Logarithmic	$MR = a\exp(-kt) + c$	Kingsly *et al*. (2007) [15]

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

$$MR = \frac{M - Me}{Mci - Me}$$

where, MR is the dimensionless moisture ratio, M, Me and Mci are the moisture content at any time (kg water/kg dm), the equilibrium moisture content (kg water/kg dm) and the initial moisture content (kg water/kg dm) respectively (Wankhade *et al*., 2012) [37].

2.3 Correlation coefficients and error analysis

The ability of the tested mathematical model to represent the experimental data was evaluated through the correlation coefficient (R^2), the reduced ($\chi2$) and the root mean square error (RMSE) parameters. The higher the R^2 and lower the $\chi2$ and RMSE values, the better is the fitting procedure (Wang *et al*., 2007 and Ozbek and Dadali, 2007) [36] [26]. The regression analysis was performed by using the SAS software. These parameters are defined as follows:

$$\chi2 = \sum \frac{(MRpre,i - MRexp,i)^2}{MRpre,i}$$

$$RMSE = \left[\frac{\frac{1}{N}\sum_{i=1}^{N}(MRexp,i - MRpre,i)^2}{N}\right]^{\frac{1}{2}}$$

Where, MRexp,i and MRpre,i are the *i*th experimental and predicted moisture ratio, respectively, N is the number of observations and z is the number of parameters.

Moisture content (Mc)

$$Mc = \frac{Mi - Md}{Mi} \times 100$$

Mi is the mass of sample before drying and *Md* is the mass of sample after drying.

Drying rate (Rd)

$$Rd = \frac{Mi - Md}{t}$$

Mi is the mass of sample before drying and *Md* is the mass of sample after drying and 't' is time in min.

3. Results and Discussion

3.1 Fitting of drying curves

The moisture content of beetroot was decreased with increased drying time at various drying temperature. It showed that the moisture removal is rapid during the initial period of drying than in next phase of drying which shows constant rate for removal of moisture (Fig. 1). The moisture removal was influenced by surface area of the slices and also by drying temperature. The results revealed that as the drying temperature is increased the moisture removal is also increased which resulted in decrease in drying time. The drying time at 50, 55, 60, 65 and 70 ºC drying temperature were 660, 630, 420, 400 and 390 min respectively for beetroot slices.

3.2 Drying rate

The drying rate rapidly increases and then slowly decreases as drying progresses (Fig. 2). In general, it was observed that drying rate reduces with time or with the reduction of moisture content. The drying process took place in the falling rate period. Similar results have been observed in the drying of different fruits and vegetables: kiwifruit (Femenia *et al*., 2009) [8]; hazelnut (Uysal *et al*., 2009) [33]; carrot pomace (Kumar *et al*., 2011) [19]; pineapple, mango, guava and papaya (Marques *et al*., 2009) [22] and apple pomace (Wang *et al*., 2007) [36].

The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of heat and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of heat and resulted in a fall in the drying rate. This indicated that the drying temperature had a crucial effect on the drying rate. Similar findings were reported in previous studies (Wang *et al.*, 2007; Soysal *et al.*, 2006 and Therdthai and Zhou, 2009) [36, 31, 32].

3.3 Modeling of drying characteristics

The first set of experiments was conducted to obtain moisture curves at different temperatures (50 to 70 ºC) as shown in Fig. 1. Moisture content decreased from 90.86 per cent to 11.67 per cent at all the temperatures whereas the drying time decreased from 660 to 360 min, lowest time at highest temperature. The first step of modeling was to define drying curves for beet. Drying rate as function of moisture content was plotted (Fig. 2). After a short initial time of sample heating, constant rate drying was observed for some time. At lower drying temperatures, constant drying rate was lower and moisture kept on diffusing to the surface resulting in lower critical moisture content. Moisture ratio as a function of drying time is given in Fig. 3. It can be seen that moisture ratio decreases exponentially with time.

The statistical results from models are summarized in Table 2. The four drying models were compared in terms of the statistical parameters R^2, adjusted R^2, χ^2 and RMSE to describe the drying curves of beetroot slices at different temperatures. The best model describing the drying process was selected based on the low RMSE, low χ^2, and high R^2, adjusted R^2. For the current experimental data, the R^2 values for the models were greater than 0.90, indicating a good fit. The R^2 and adjusted R^2 values for Logarithmic model was varied between 0.932 and 0.963, 0.926 and 0.960 respectively, χ^2 values between 0.07 and 0.11, and *RMSE* values between 0.151 and 0.208. Based on the criteria of the highest R^2, adjusted R^2, lowest RMSE and χ^2, the Logarithmic model was selected as the most suitable model to represent the thin-layer drying behaviour of beetroot samples.

Table 2: Results of the model fitting statistics of various thin layer drying models

	Temp (⁰C)	k	n	R^2	Adj R^2	P	χ^2	RMSE	MBE	% Error Modulus
Page	50	0.0954 ± 0.0662	-0.1715 ± 0.0116	0.912	0.908	1.4E-12	0.029	0.045	1.93082E-16	0.118
	55	0.0895 ± 0.0582	-0.1539 ± 0.0103	0.918	0.914	2.5E-12	0.017	0.0388	0.001693468	0.053
	60	0.0795 ± 0.0755	-0.2288 ± 0.0144	0.955	0.951	1.9E-09	0.013	0.0401	2.53765E-16	0.081
	65	0.0773 ± 0.0947	-0.2099 ± 0.0178	0.914	0.908	2.6E-08	0.022	0.0521	3.25665E-16	0.123
	70	0.0738 ± 0.0923	-0.2358 ± 0.0178	0.941	0.936	4.2E-08	0.016	0.0472	2.03541E-16	0.118
Modified Page	50	-0.5562 ± 0.0662	-0.1715 ± 0.0116	0.912	0.908	1.4E-12	0.029	0.045	1.93082E-16	0.120
	55	-0.5815 ± 0.0582	-0.1539 ± 0.0103	0.918	0.914	2.5E-12	0.018	0.0388	1.00929E-17	0.070
	60	-0.3475 ± 0.0755	-0.2288 ± 0.0144	0.955	0.951	1.9E-09	0.013	0.0401	2.53765E-16	0.080
	65	-0.3683 ± 0.0947	-0.2099 ± 0.0178	0.914	0.908	2.6E-08	0.022	0.0521	3.25665E-16	0.120
	70	-0.3128 ± 0.0923	-0.2358 ± 0.0178	0.941	0.936	4.2E-08	0.016	0.0472	4.44089E-16	0.110
	Temp (⁰C)	**k**	**a**	**R^2**	**Adj R^2**	**P**	**χ^2**	**RMSE**	**MBE**	**% Error Modulus**
Henderson and Pabis	50	-0.1715 ± 0.0116	10.4855 ± 0.0662	0.912	0.908	0	0.029	0.0450	1.93082E-16	0.120
	55	-0.1539 ± 0.0103	11.1721 ± 0.0582	0.918	0.914	0	0.018	0.0388	1.00929E-17	0.070
	60	-0.2288 ± 0.0144	12.5738 ± 0.0755	0.955	0.951	0	0.013	0.0401	2.53765E-16	0.080
	65	-0.2099 ± 0.0178	12.9343 ± 0.0947	0.914	0.908	0	0.022	0.0521	3.25665E-16	0.120
	70	-0.2358 ± 0.0178	13.5582 ± 0.0923	0.941	0.936	0	0.016	0.0472	4.44089E-16	0.110
Logarithmic	50	-0.7138 ± 0.0393	8.0546 ± 0.2241	0.94	0.937	2.5E-14	0.11	0.1523	3.86E-16	0.180
	55	-0.7548 ± 0.042	8.9848 ± 0.2381	0.942	0.939	8.4E-14	0.096	0.1584	7.47E-16	0.130
	60	-0.9487 ± 0.0539	8.8196 ± 0.2834	0.963	0.96	6.2E-10	0.067	0.1505	2.37905E-15	0.130
	65	-0.9475 ± 0.0712	9.3326 ± 0.3785	0.932	0.926	6E-09	0.113	0.2084	2.66454E-15	0.230
	70	-1.0186 ± 0.066	9.3377 ± 0.3425	0.956	0.952	8.5E-09	0.075	0.175	1.1273E-15	0.180

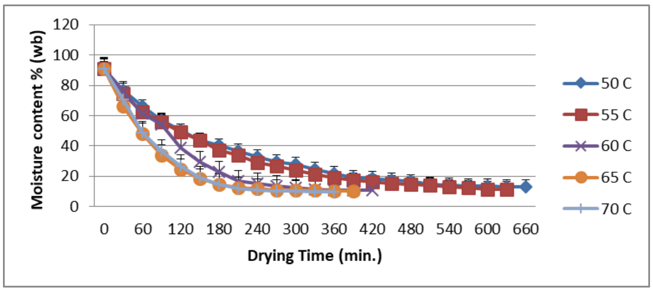

Fig 1: Moisture content of beetroot slices influenced by drying time at different drying temperatures

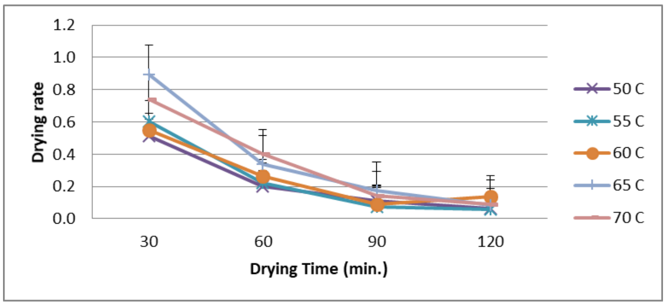

Fig 2: Drying rate of beetroot slices influenced by drying time at different drying temperatures

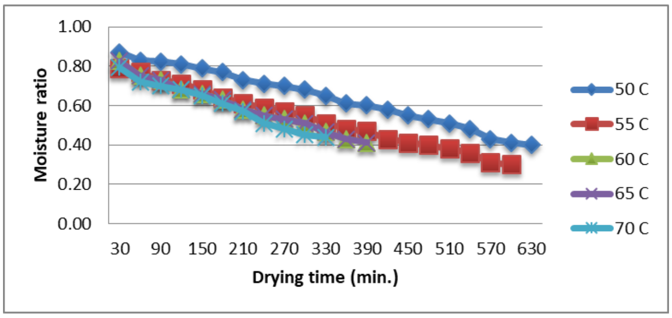

Fig 3: Moisture ratio of drying of beetroot slices influenced by drying time at different drying temperatures

4. Conclusion

The drying characteristic of beetroot under hot air were studied. The increase in air drying temperature decreased the drying time. Total drying time considerably reduced with the increase in drying air temperature. Drying took place in the falling rate period. Based on the findings in the present experiment it can be concluded that Logarithmic model was found to be a better model for describing the drying characteristics of beetroot at all temperatures. Finally, it can be concluded that thin layer drying can be used for the preparation and preservation of beetroot slices.

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