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THIN LAYER CONVECTIVE DEHYDRATION KINETICS OF BEETROOT (*BETA VULGARIS* L.*)* LEAVES

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***Abstract*- The effect of blanching and drying air temperature on drying kinetics and rehydration ratio of beetroot leaves were investigated. It has been observed that both blanching and drying air temperature have significant effect on drying time and rehydration ratio. The shortest drying time and lower rehydration ratios were for blanched samples as compared to un-blanched ones. Out of the various thin layer models evaluated for the dehydration kinetics, Wang and Singh model was best fitted to drying data. The activation energy of blanched and unblanched samples was 15.7913 and 20.9221 kJ/mol, respectively.**

***Index Terms*- Beetroot leaves, drying kinetics, activation energy, and rehydration ratio.**

I. INTRODUCTION

Beetroot (*Beta vulgaris* L.*)* belonging to the *Chenopodiaceae* family is indigenous to Asia and Europe. Beetroot leaves have more nutritional value than their roots and rich in carbohydrates, protein, fiber, minerals like iron potassium, magnesium, copper, calcium, vitamins like A, B_6, E, and C and natural antioxidant like β – carotene and vitamin A [1]. Beetroot leaves are rich source of iron than spinach [2]. Beetroot leaves have remained underutilized due to lack of awareness of nutritional value of leaves [1].

Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously [3]. The materials are dried using several drying techniques but thin layer drying is most popular due to faster rate and minimum loss of nutrients as compared to other drying techniques [4]. Advantage of drying of vegetable is that the vegetable can be easily converted into fresh like form by rehydration and can be used in off season [5]. Dehydration is the useful techniques to increase the shelf life of perishable food for further use [6]. Many empirical models have proposed to describe the drying process out of them; thin-layer drying models have been widely used to describe the drying process. Many studies have emphasized drying kinetics and drying models for fruits and vegetables like coriander [7], fenugreek [8], peach [9], apricot [10], yam [11] and carrot [12]. Study on drying kinetics and activation energy of beetroot leaves in thin-layer drying has not been reported yet. The objective of this study was to study the effect of blanching on the drying kinetics, activation energy and rehydration ratio of beetroot leaves powder.

II. MATERIAL AND METHOD

Experimental plan

Fresh beetroot (*Beta vulgarus* L.) leaves were procured from local market of Sangrur (Punjab). The leaves washed with tap water followed by steam blanching for 2 minutes [13]. The blanched leaves were immediately cooled down under running tap water to remove excess heat and were placed on absorbent paper to absorb the surface water before drying. The dehydration experiments were conducted in a pilot-scale cabinet dryer at drying air temperatures of 50, 60, 70 and 80°C. The dryer was started before drying experiment to achieve the steady state preset temperature conditions. For each experiment 200 gm of beetroot leaves were uniformly distributed in thin layer on perforated tray. Sample weights were recorded at regular interval of time. Drying process was continued until the achievement of final moisture content in the range 3-6% (d.b). The dried leaves were packed into polythene bags.

Empirical Modeling fitting to drying data

The drying data of beetroot leaves was fitted to the various empirical models given in table.1. The moisture content of drying beetroot leaves sample at time t can be transformed into moisture ratio by the following equation:

$$MR = \frac{M - M_e}{M_o - M_e} \qquad (1)$$

The drying of leaves takes long time drying and for long drying time, the term equilibrium moisture content (M_e)

can be neglected in the calculation of moisture ratio [14, 15].

Table.1 List of Models with reference

Model name	Models	Reference
Newton	$MR = \exp(-Kt)$	[16]
Magee	$MR = a \times t^{1/2}$	[17]
Wang and Singh	$MR = 1 + a \times t + b \times t^2$	[18]
Aghabashlo	$MR = \exp\left(-k_1 \times t / 1 + k_2 \times t\right)$	[19]
Two term exponential	$MR = a \times \exp(-k \times t) + (1-a) \times \exp(-k \times a \times t)$	[20]
Weibull	$MR = \exp\left(-\left(\frac{t}{a}\right)^b\right)$	[21]

The goodness of fit of the selected empirical models to the experimental data was evaluated with the correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE).

Calculation of activation energy

Arrhenius type equation is used for the calculation of activation energy.

$$K = K_o \exp.\left(\frac{-E_a}{R_u(T + 273.15)}\right)$$

Where, K_o is the pre-exponential factor of Arrhenius equation in m^2/s, E_a is the activation energy in kJ/mol, R_u is the universal gas constant having value 8.314 J/mol K, and T is the drying air temperature in °C.

Rehydration ratio

Rehydration ratio was the one of important factor in the dehydrated products determined by method [22]. Dehydrated samples (5 g each) were put into a beaker and 50 ml of warm (60 °C) water was added. After 30 minutes, drained weight of dehydrated material was taken. The weight after draining was recorded and rehydration ratio was calculated using formula.

$$\text{Rehydration ratio} = \frac{Weight\ of\ rehydrated\ sample}{Weight\ of\ dehydrated\ sample} \times 100$$

III. Results And Discussions

A. *Effect Of Blanching On Drying Behavior*

The blanching of beetroot leaves has resulted in significant reduction in drying time at all the preselected drying air temperature ($p < 0.05$, Table.1). The total drying time was 500 minutes for blanched sample in comparison to 560 minutes for unblanched sample at 50 °C temperatures (Table.1). The reduction in drying time due to blanching has also been observed at other preselected temperature i.e. 60, 70 and 80 °C. The reduction of drying time due to the blanching might be because of the rupturing of cell structure of leaves during blanching, which facilitate the removal of moisture from leaves. [23] Also reported the increase in evaporation rate from carrots due to structural changes and enlargement of the pore openings in the product during blanching. [24] Also reported that blanching reduced the skin thickness i.e. resistance to mass transfer at the surface of the product. Fig.1 indicates that moisture content reduction of blanched sample was faster as compared to unblanched sample.

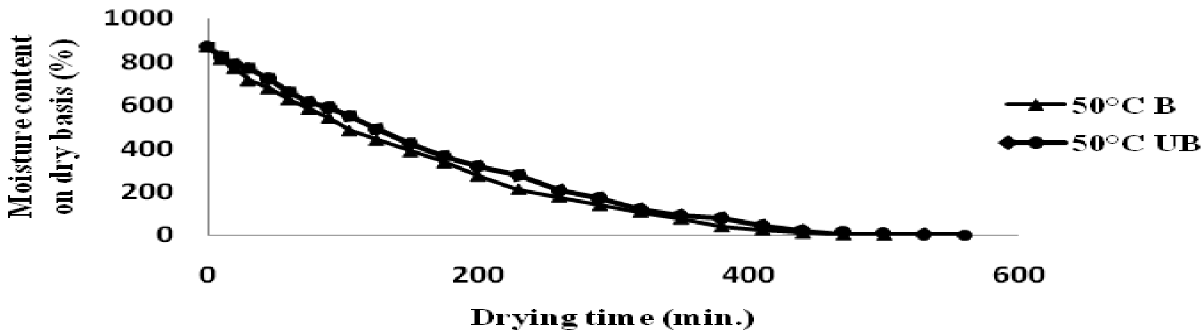

Fig.1 Drying curve for blanched and unblanched beetroot leaves at 50°C drying air temperature.

Blanching pretreatment has resulted significantly increase in drying rate of blanched beetroot leaves sample than the unblanched beetroot leaves sample. Fig.2 indicates that the drying rate decreased with decrease in moisture content available in the product in both blanched and unblanched samples. During drying, the water moves from interior to the surface followed by evaporation from the surface. During initial drying period, the drying rate was high due to presence of free moisture on the surface. The decrease in drying rate with decrease of moisture content is due to less availability of water at the surface because of slow diffusion of moisture from interior to the surface.

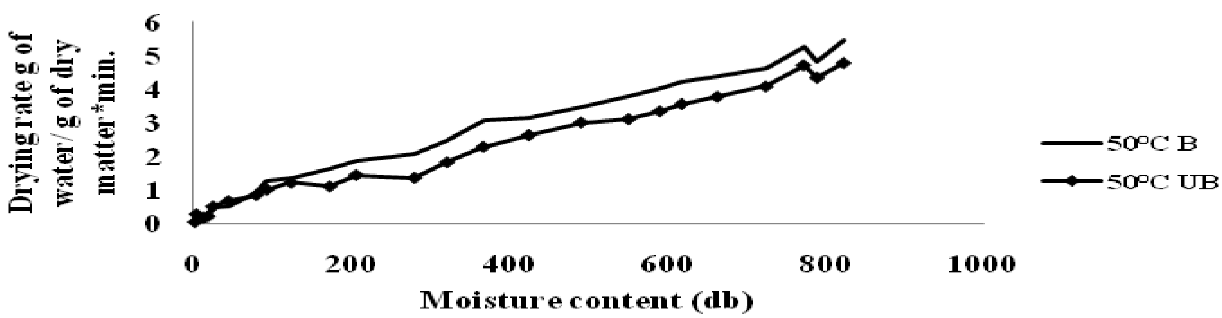

Fig.2 Drying rate versus moisture content (db) of blanched and unblanched beetroot leaves at different temperatures.

B. Effect Of Temperature On Drying Behavior

Generally higher the drying air temperature, higher will be the drying rate and shorter will be drying time. The drying times to reach the final moisture content of sample for the unblanched beetroot leaves dried at 50 °C temperatures was 560 minutes. The reduction of drying time was 10.71, 26.78 and 37.5 % at 60, 70 and 80 °C, respectively. Drying times to reach the final moisture content in the range of 3-6 % of sample for the blanched beetroot leaves dried at 50 °C temperatures was 500 minutes (Table.1). Drying time for blanched sample dried at 60, 70 and 80°C reduced by 4, 24 and 36%, respectively**.** Similar findings have been reported by [25, 26, 27] for fruit and vegetable products drying.

Table.1 Drying times of blanched and unblanched beetroot leaves at different temperature

Temperature	**Drying time (min)**	**Drying time (min)**
(°C)	(B)	(UB)
50	500	560
60	440	500
70	380	410
80	320	350

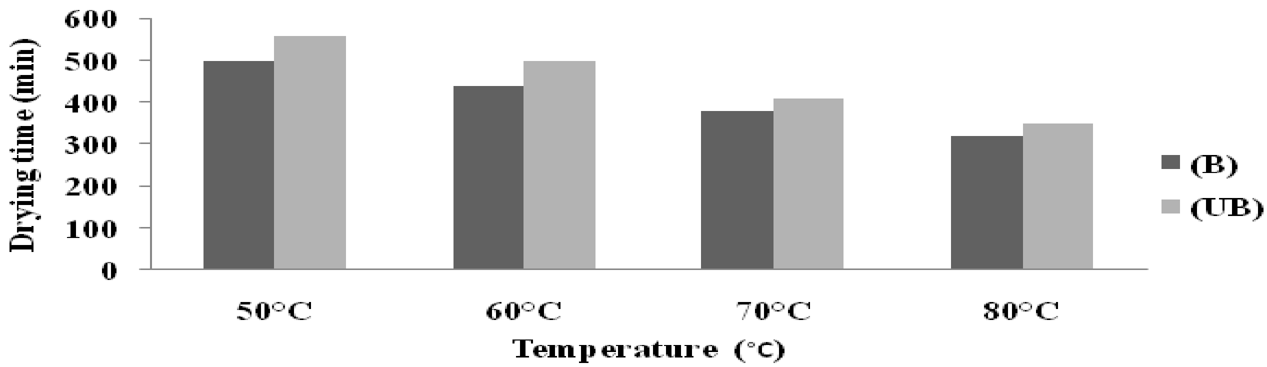

Fig.3 Effect of blanching and drying air temperature on drying time (min.).

In case of unblanched samples, the average drying rate increases from 1.87 to 2.85 (g of water/ g of dry matter-min) with increase in temperature from 50-80 °C; and in case of blanched samples average drying rate increases from 2.55 to 3.56 (g of water/ g of dry matter-min) with increase in drying temperature from 50 to 80°C. Fig.4.4 shows that an increasing drying temperature speeds up the drying process by increasing drying rate.

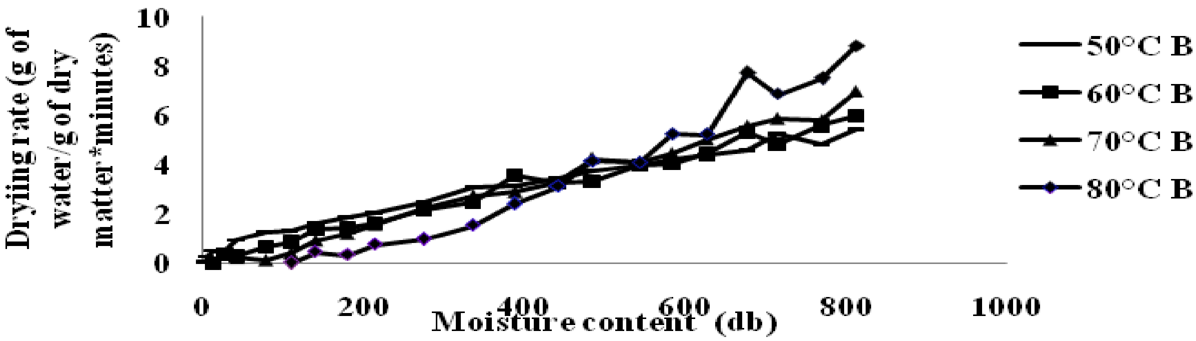

Fig.4 Drying rate versus moisture content (db) of blanched beetroot leaves at different temperatures.

It has been observed that the moisture ratio reduced exponentially as the drying time increased. Moisture ratio reduced as the drying time increased [28].

At higher drying temperature the moisture ratio decreased faster rate due to the increase in air heat supply rate to the leaves and the acceleration of moisture migration. Similar result reported by [29] during study on bay leaves. Fig.5 shows the effect of temperature on moisture ratio of blanched beetroot leaves. Similar result observed in case of unblanched beetroot leaves drying at selected temperature.

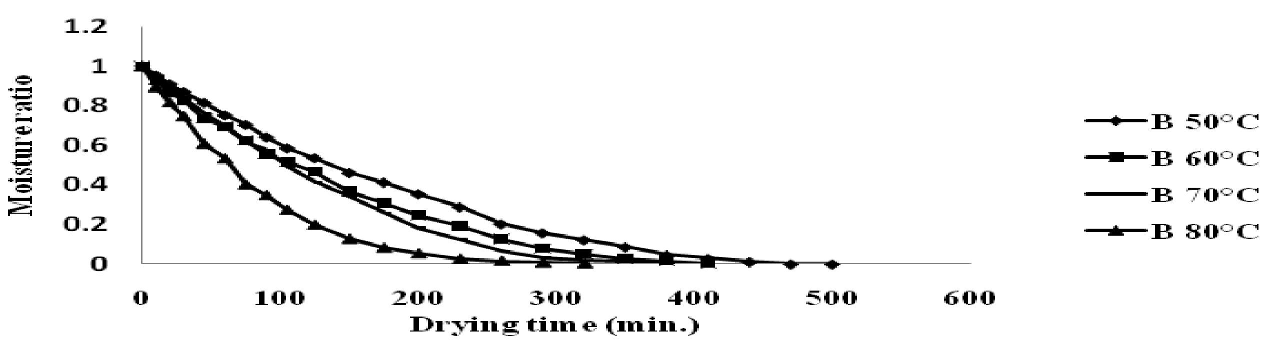

Fig.5 Moisture ratio versus drying time of blanched beetroot leaves at different temperatures.

C. Fitting of drying data to empirical models

The moisture content data obtained at different temperature were converted to moisture ratio (MR) and fitted into the empirical models listed in Table.1.

Table.2 Values of the constants and exponents of empirical models for blanched beetroot leaves.

Sr. no	Model Name	Temperature (°C)	Coefficient	χ2	RMSE	R^2
1	Newton	50	k = 0.0054	0.0015	0.0380	0.9938
		60	k = 0.0061	0.0013	0.0351	0.9945
		70	k = 0.0066	0.0026	0.0493	0.9895
		80	k = 0.0092	0.0009	0.0296	0.9961
2	Magee	50	a = 0.8432, k = -0.0041	0.0096	0.0937	0.9608
		60	a = 0.8230, k = -0.00459	0.0105	0.0975	0.9559
		70	a = 0.8585, k = -0.0055	0.0101	0.0953	0.9603
		80	a = 0.7549, k = -0.0062	0.0218	0.1388	0.9096
3	Wang & Singh	50	a = -0.0044, b = 0.000005	0.0003	0.0166	0.9988
		60	a = -0.00518, b = 0.000007	0.0005	0.0202	0.9998
		70	a= -0.0057, b = 0.000008	0.0001	0.0070	0.9998
		80	a = -0.0085, b = 0.000001	0.0015	0.0364	0.9941
4	Aghabashlo	50	k_1 = -16.9942, k_2= -17.00	0.0016	0.0380	0.9937
		60	k_1= -13.2948, k_2= -13.30	0.0014	0.0351	0.9945
		70	k_1= 6.5726, k_2= 6.6557	0.0027	0.0493	0.9895
		80	k_1= -50.4743, k_2= -50.4864	0.0010	0.0296	0.9961
5	Two Term Model	50	a = 0.0017, k = 3.3719	0.0011	0.0325	0.9936
		60	a = 0.0025, k = 2.8688	0.0014	0.0354	0.9943
		70	a = 0.0017, k = 4.4092	0.0028	0.0497	0.9894
		80	a = 0.021, k = 5.5961	0.0010	0.0300	0.9960
6	Weibull	50	a =170.6770, b =1.2019	0.0004	0.0197	0.9983
		60	a =143.6183, b =1.1617	0.0006	0.0236	0.9978
		70	a =133.3169, b =1.2959	0.0000	0.0213	0.9981
		80	a =83.2792, b =1.1834	0.0002	0.0121	0.9994

Table.3 Values of the constants and exponents of empirical models for unblanched beetroot leaves.

Sr. no	Model Name	Temperature (°C)	Coefficient	χ2	RMSE	R^2
1	Newton	50	k = 0.0059	0.0021	0.0447	0.9916

		60	k = 0.0070	0.0018	0.0412	0.9927
		70	k = 0.0075	0.0019	0.0425	0.9923
		80	k = 0.0121	0.0017	0.0403	0.9932
2	Magee	50	a = 0.8485, k = -0.0038	0.0105	0.0981	0.9586
		60	a = 0.8392, k = -0.004128	0.0110	0.1002	0.9559
		70	a = 0.8551, k = -0.0048	0.0108	0.0987	0.9574
		80	a = 0.8026, k = -0.0054	0.0188	0.1299	0.9265
3	Wang & Singh	50	a = -0.0040, b = 0.000004	0.0001	0.0092	0.9997
		60	a = -0.0045, b = 0.000005	0.0000	0.0138	0.9992
		70	a = -0.0049, b = 0.000006	0.0002	0.0127	0.9994
		80	a = -0.0066, b = 0.000001	0.0061	0.0737	0.9978
4	Aghab-Ashlo	50	k_1 = -5.6257, k_2 = -5.6310	0.0022	0.0447	0.9916
		60	k_1 = -17.911, k_2 = - 17.9171	0.0019	0.0412	0.9927
		70	k_1 = -10.307, k_2 = -11.3136	0.0020	0.0425	0.9923
		80	k_1 = -13.824, k_2 = -13.8334	0.0018	0.0403	0.9932
5	Two Term Model	50	a = 0.00174, k = 3.071	0.0022	0.0450	0.9915
		60	a = 0.0020, k = 2.9743	0.0019	0.0416	0.9925
		70	a = 0.0015, k = 4.174	0.0020	0.0429	0.9921
		80	a = 0.0017, k = 5.1358	0.0019	0.0408	0.9930
6	Weibull	50	a =188.80, b =1.2597	0.0004	0.0195	0.9985
		60	a =166, b =1.2269	0.0005	0.0209	0.9982
		70	a =153.14, b =1.2610	0.0002	0.0124	0.9994
		80	a =109.9670, b =1.2576	0.0002	0.0128	0.9994

In case of blanched beetroot leaves drying Wang and Singh model best fitted in drying data at 70 °C temperature (Table.3) and in case of unblanched beetroot leaves sample Wang and Singh model best fitted in drying data at 50 °C temperature (Table.4).

D. Effect blanching on activation energy

Activation energy is the minimum amount of energy required to initiate moisture diffusion from a biomaterial. The activation energy of beetroot leaves has been determined from the slope of $\log_{10}K$ versus 1/ (T + 273.15) plot (Fig.6). The slope of the line is (E_a/R) and the intercept equals to $\log_{10}$ (K_0). The activation energy for blanched and unblanched samples found as 15.7913 and 20.9221 kJ/mol, respectively (Table.4.2). [30] reported 12.5 kJ/mole of activation energy for moringa leaves during convective drying. The lowering of activation energy due to blanching might be due to the reason that the water can be removed from the sample by less energy due to the rupture of skin and cell structure during blanching. [31] Also reported the decrease of activation energy due to blanching of bell pepper. Therefore, the blanching treatment can be used to minimize the energy requirement for the drying process of beetroot leaves.

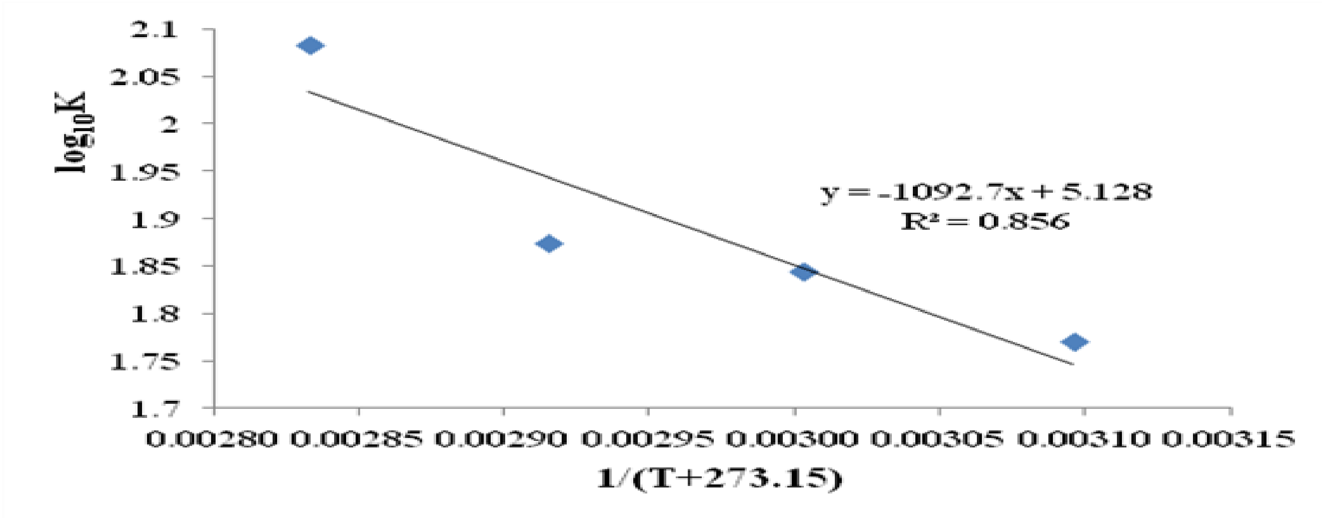

Fig.6 Arrhenius-type relation between Newton model constant K (at temperature T) and reciprocal of absolute temperature (1/ (T+273.15)) in case of Unblanched sample.

Table.4 Activation energy of blanched and unblanched beetroot leaves sample.

Sample	Activation energy(kJ/mol)
Blanched	15.7913
Unlanched	20.9221

(Note: Activation energy has been calculated from Newton model constant K shown in Table.2 and 3)

E. Rehydration ratio

The rehydration ratio was assessed because the incorporation of beetroot leaves powder into food products requires rehydration. Table.5 indicates that the blanching pretreatment resulted in decrease in rehydration ratio. It might be due to damage of beetroot leaves tissues leading to loss of permeability and water absorption. [32] Also reported the decrease of rehydration ratio of dried lettuce leaves after blanching. [33] Also revealed same results in case of dried amaranthus leaves.

Table.5 also indicates the increase of drying air temperature has resulted in decrease of rehydration ratio of beetroot leaves powder. It might be due to cellular rupture during drying resulted into loss of water absorption capacity of BRLP. [34] Also revealed the cellular rupture and dislocation occur during drying result in loss of tissue integrity producing dense structure, reduced hydrophilic properties. So more the temperature more will be the tissue damage and lower the rehydration ratio.

Table.2 Rehydration ratio of beetroot leaf powder at different temperature

Property		**Beetroot leaves powder**			
		50°C	60°C	70°C	80°C
Rehydration ratio	UB	$4.72{\pm}0.007^{a}$	$3.47{\pm}0.005^{b}$	$3.18{\pm}0.003^{c}$	$3.06{\pm}0.057^{d}$
	B	$3.57{\pm}0.011^{a}$	$3.36{\pm}0.003^{b}$	$3.09{\pm}0.010^{c}$	$2.01{\pm}0.119^{d}$

(Mean±S.D. with different superscripts in a row differ significantly ($p < 0.05$))

IV. CONCLUSION

According to the experimental result this study revealed that the blanched sample required lower drying time than the unblanched sample. The drying time decrease with increase of drying air temperature. It was observed that drying process took place in falling rate period. Wang and Singh model gave the best representation of drying data at all experiment in both blanched and unblanched beetroot leaves sample. The activation energy for blanched and unblanched samples was found as 15.7913 and 20.9221 kJ/mol, respectively. Rehydration ratio of blanched sample was lower than the unblanched sample.

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