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EFEECT OF HOT-AIR DRYING ON PHYSICAL PROPERTIES AND COLOUR CHARACTERISTICS OF BEETROOT *(Beta vulgaris* L.)

Mohammad Azam* and Sheela Pandey

Department of Post-Harvest Process & Food Engineering, College of Agricultural Engineering, Jawaharlal Nehru Agricultural University, Jabalpur - 480 001, Madhya Pradesh (India)
**E-mail*:*mazam226@gmail.com*

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ABSTRACT

Beetroot is recognized as health promoting food due to presence of essential components such as vitamins, minerals, phenolics, carotenoids, nitrate, ascorbic acids and betalains that promote health. Good quality beetroot samples (100) were randomly taken and characterized for physical properties *viz*., shape, length, width and thickness. Derived dimensional properties like geometric diameter, equivalent diameter, arithmetic diameter, sphericity, surface area, aspect ratio, bulk density, true density, peel thickness, angle of repose and packing coefficient were calculated. These properties are necessary for designing the equipment for harvesting, sorting, separating and packing. The mean values of sphericity and surface area were found to be 0.91 and 79.63 cm^2. The average values of aspect ratio, peel thickness and angle of repose were 0.94, 1.06 mm and 40.67°, respectively. The drying experiments were carried out under three air temperatures of 40, 50 and 60°C, air velocity of 1.0 m/s beetroot slice thickness of 2 mm. The colour parameters for colour change of the materials were quantified by Hunter (*Lab*) system. These values were also used to calculate the total colour change, chroma, Hue angle and browning index. It was observed that *L, a, b* and chroma were fitted to first order kinetics model, whereas ΔE and Hue angle followed zero order kinetic model.

Keywords: Beetroot, browning index, chroma, colour parameters, hot air drying, Hue angle, physical properties

INTRODUCTION

Beetroot (*Beta vulgaris* L.) belongs to the family Chenopodiaceae and has originated from Asia and Europe. Chenopodiaceae family includes approximately 1400 species divided into 105 genera. Beetroot is a flowering true biennial or rarely perennial plant and has several varieties with bulk colours ranging from yellow to red (Chhikara *et al*., 2018). Beetroot is a root vegetable and available throughout the year. It is a cool season vegetable with optimum temperature range 15 to 19°C and is fairly tolerant to high temperature. The low temperature promotes the development of deep red pigmentation in beetroot (Yashwant, 2015). Harvest time of beetroot is 75-90 days in summer and 100-120 days in winter. The sugar content of beetroot depends on the nitrogen availability and nitrogen is applied in the early stages of growth (Yashwant, 2015).

To design a machine for handling, cleaning, grading, conveying, processing, packaging and storage, the physical properties of agricultural products must be known (Tabatabaeefar, 2003; Tabatabaeefar and Rajabipour, 2005). Among these physical characteristics, mass and volume are important in defining the sizing systems (Peleg and Ramraj, 1975; Khodabandehloo, 1999). Information regarding dimensional attributes is used in describing the fruit shape which is often necessary in horticultural research for many purposes including cultivar descriptions in application for plant variety rights or cultivar registration (Schmidt *et al*., 1995; Beyer *et al*., 2002). Quality differences in fruits can often be detected by differences in density. When fruits are transported hydraulically, the design fluid velocities are related to both density and shape. Fruit volume must be known for accurate modeling of heat and mass transfer during cooling and drying. Awareness of fruit surface area would be useful in determination of mass of the cuticular membrane per unit fruit surface area (Peschel *et al*., 2007).

The colour observed by human beings is the perception of wavelengths coming from the surface of object on the retina of eyes (Tijskens *et al*., 2001). When light strikes an object, it is either reflected or absorbed or transmitted, but it is the reflected light which determines the colour of a material. Therefore, appearances can change depending on the amount of light, the light source, the observer's angle of view, size and background differences (Giese, 2000). However, standardized instrumental colour measurement correspond to the visual assessments of food colour and it is a critical objective parameter that can be used as a quality index (raw and processed foods) for determining the conformity of food quality to specifications and for analysis of quality changes as a result of food processing, storage and other factors. Several colour scales have been used to describe colour, Hunter colour parameter (*L, a, b*) has previously proved valuable in describing the visual colour deterioration and providing useful information for quality control in vegetable and fruit products (Lopez-malo *et al.*, 1998; Giese, 2000). The maintenance of naturally coloured pigments in thermally processed and stored foods has a major challenge in food processing. The majority of works on kinetics of colour change in food materials report zero- and first-order degradation reaction kinetics (Majumdar, 2000).

Beetroot powder or extracted pigments are used industrially for improving the red colour of tomato pastes, sauces, soups, desserts, jams, jellies, ice creams, sweets, and breakfast cereals (Koul *et al*., 2002; Roy *et al.*, 2004). Beetroot is a good source of red and yellow pigments known as betalains. Betalains consist of betacyanins (red) and betaxanthins (yellow). The major betacyanin in beetroot is betanin and accounts for 75-95% of red pigment (Von Elbe *et al*., 1972). Betanins reportedly have some antioxidant activity and are effective in inhibiting lipid peroxidation. Thus, it is suggested that red beet products consumed regularly in diet may provide protection against certain oxidative stress-related disorders in humans and improve digestion and blood quality (Kanner *et al*., 2001; Butera *et al*., 2002; Herbach *et al*., 2004; Azeredo, 2009). Therefore, the retention of colour pigments is important for health benefits as well as visual appeal. Knowledge of kinetic parameters of colour degradation during thermal processing is also important in optimizing the process parameter. The present study was aimed to study some physical properties of beetroot and improve the optical properties of beetroot slices during hot air oven drying so as to predict colour changes with time by foregoing drying techniques.

MATERIALS AND METHODS

Physical parameters of fresh beetroot

The experiment was conducted in the Laboratory of the Department of Post-Harvest Process and Food Engineering, College of Agricultural Engineering, J.N.K.V.V., Jabalpur, Madhya Pradesh (India). Fresh beetroots were procured from local market in Jabalpur. Disease free and quality beetroots were selected and washed with tap water to remove the dust and dirt over the surface. Beetroots (100) were selected for the determination of physical properties.

Measurement of axial dimension

To determine the average size of fruits, three linear dimensions, namely length (L) [equivalent distance from stem (top) to calyx (bottom)]; width (W) [the longest dimension perpendicular to L] and thickness (T) [the longest dimension perpendicular to L and W] were measured by using Aerospace Digital Caliper with balance of 0.001 g accuracy. The mass of beetroots was determined with an electronic balance (Make-Citizen, Model No: CY-3600).

Diameter

The diameter was calculated by using Eq. (1), (2) and (3), respectively, (Mohesnin, 1986):

$$\text{Geometric diameter } (D_g) = (LWT)^{1/3} \quad (1)$$

$$\text{Equivalent diameter } (D_p) = [L\frac{(W+T)^2}{4}]^{1/3} \quad (2)$$

$$\text{Arithmetic diameter } (D_a) = \frac{(L+W+T)}{3} \quad (3)$$

Sphericity

The sphericity, S_p (%) defined as the ratio of surface area of a sphere having the same volume as that of fruit to the surface area of fruit, was determined using the following formula of Mohsenin (1986):

$$S_p = \frac{\sqrt[3]{(LWT)}}{L} \quad (4)$$

Surfacearea

The surface area of fruit was calculated by as per the following formula of Mohsenin (1986):

$$S = \pi(D_g)^2 \quad (5)$$

Aspectratio

The aspect ratio, R_a was calculated by as per the formula given by Omobuwajo *et al.* (1999):

$$R_a = \frac{W}{L} \quad (6)$$

Packing coefficient

Packing coefficient is defined as the ratio of the volume of fruit packed to the total volume; and is calculated by the following formula of Topuz *et al*. (2004):

$$\lambda = \frac{V}{Vo} \quad (7)$$

where: λ = packing coefficient; V = true volume of fruit; Vo = volume of the box containing fruits

Bulk density

The bulk density is the mass of group of individual particles divided by the space occupied by the entire mass (Mohsenin, 1986), including the air space; and was determined using the following relationship. It was measured in a 500 mL flask. Beetroots were poured inside the flask and shaked 10 times manually to fill the pore spaces.

$$\text{Bulk Density} = \frac{\text{Mass of sample (g)}}{\text{Volume of flask occupied by the sample}(cm^3)} \quad (8)$$

True density

True density is defined as the ratio between the mass of a material and its true volume, and was determined by toluene (C_7H_8) displacement method. Toluene (500 mL) was used in place of water, because it is not absorbed by crop material. The volume of toluene displaced was found by immersing beetroot of known mass in toluene (Mohsenin, 1986).

$$\text{True density } (g\ cm^{-3}) = \frac{\text{Weight of sample}}{\text{Volume displaced}} \quad (9)$$

Angle of repose

The angle of repose of beetroot is the maximum angle by which root heap can be made. It was measured by making the heap of 2 kg beetroot with hollow cylinder and was measured by drawing tangent to slope and the horizontal line. Beyond this angle root have tendency to slide (Mohsenin, 1986).

$$\text{Angle of repose } \theta = \tan^{-1}(2h/D) \qquad (10)$$

where, h = the height of pile and D = the base (dia)

Initial moisture content

The initial moisture content of beetroot was determined by standard AOAC method (2005) on wet basis.

Colour characteristics of beetroot slices

Preparation of samples and dryer for testing: Drying treatment was given in a hot air oven (M.A. Trading Co., Gwalior). Experiments were conducted 30 min after the system was turned on to reach to a steady state condition. The trays holding the samples were carefully put in dryer. Fresh beetroots were procured from local market of Jabalpur (India) and leaves removed from their end portions with sharp edge knife. After washing in tap water, the samples were sliced to the thickness 2 mm by adjusting the opening of slicer with a Vernier caliper (Aerospace Vernier Caliper, 0-150 mm range) having a least count of 0.1 mm. The beetroot slices (200 g) were uniformly spread in a tray and kept inside an oven. The experiments were conducted in a completely randomized block and three replications were taken in each experiment according to preset air temperature and time schedule and the data presented as average of these replications. The drying experiment was conducted at three air temperatures of 40, 50 and 60°C with 1.0 m/s air velocity. The hot air drying was applied until the weight of sample was reduced to a level corresponding to moisture content of 0.5 db.

Measurement of colour parameters: Sample colour (*Lab*) was measured before drying and at 30 min time intervals during drying period by a Hunter-Lab Color Flex, CX2017 model colorimeter (Hunter Lab, Reston, VA). This system uses three values (*Lab*) to describe the precise location of a colour inside a three-dimensional visible colour space. The colorimeter was calibrated against standard white and black plates before each actual colour measurement. For each sample at least three measurements were taken at different positions. The measurements were displayed in '*L', 'a'* and '*b*' values which represent light-dark spectrum with a range from 0 (black) to 100 (white), the green red spectrum with range from -60 (green) to +60 (red) and the blue-yellow spectrum with range from -60 (blue) to +60 (yellow) dimensions, receptively. The total colour change is given by colour difference (ΔE) in terms of spatial distance between two colour points interpreted in colour space (Hunter, 1987):

$$\Delta E = [(L_o - L_i) + (a_o - a_i) + (b_o - b_i)]^{1/2} \qquad (11)$$

The subscript o and i denote the colour parameters of fresh and dried beetroot slices, respectively. The higher ΔE represents greater colour change from the fresh beetroot.

The Hue angle is defined as a colour wheel, with red-purple at the angle of 0°, yellow at 90º, bluish-green at 180° and blue at 270°. It is given by the ratio the ratio a/b or by one of the angles (Lopez-malo *et al*., 1998):

$$\text{Hue angle } (\theta) = \tan^{-1}(b/a) \qquad (12)$$

or

$$\text{Hue angle } (\theta) = \tan^{-1}(a/b) \qquad (13)$$

The chroma represents colour saturation which varies from dull at low chroma values to vivid colour at high chroma values (Hunter, 1987). Chroma is the saturation given by the distance from the colour point C to the white point which is (Lopez-malo *et al*., 1998).

$$\text{Chroma } (C^*_{ab}) = (a^2 + b^2)^{1/2} \qquad (14)$$

Browning index (BI) represents the purity of brown colour and is considered as an important parameter associated with browning (Lopez-malo *et al*., 1998).

$$BI = \frac{[100(x-0.31)]}{0.17} \quad (15)$$

$$x = \frac{(a+1.75L)}{(5.645+a-3.012b)} \quad (16)$$

Statistical analysis

Experimental data for different parameters were fitted to two kinetic models (zero- and first-order models) and processed by using Microsoft Excel 2007. The majority of works on the kinetic of colour change of food material report zero order Eq. (20) or first order Eq. (21) degradation reaction kinetics (Majumdar, 2000).

$$C = C_o \pm k_o t \quad (17)$$

$$C = C_o \exp(\pm k_1 t) \quad (18)$$

Where 'C' is the measured value of colour variables at time t, 'C_o' the initial value of colour variables at time zero, t the drying time (min), k_o the zero-order kinetic constant (min^{-1}) and k_1 is the first order kinetic constant (min^{-1}). (+) and (-) indicate formation and degradation of quality parameter, respectively. Hunter colour parameter (*Lab*) has previously proved valuable and describing usual colour deterioration and provides useful information for quality control in fruit and vegetables. In statistics, the coefficient of determination R^2 is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information.

RESULTS AND DISCUSSION

The initial moisture content in all the replication of beetroot was 89.5% (wb). The shape of beetroot was either spherical or ellipsoidal. The statistical analysis of various physical properties was summarized in Table 1.

Effect of hot air temperature on colour kinetics of beetroot

The values of *L*, *a*, *b* and total colour change (ΔE) obtained during hot air drying and the model data are presented in Fig. 1-8. Fig. 1 and 2 revealed that '*L*' value decreased with drying time. L value has been taken as a measurement of browning (Avila and Silva, 1999), which reduced from 26.94 to

Table 1: Physical characteristics of beetroot at 89.5% (wb) moisture content

Properties	No. of Observation	Specification			
		Mean	Maximum	Minimum	SD
Length (cm)	100	5.53	8.50	4.10	0.69
Width (cm)	100	5.18	9.70	3.90	0.78
Thickness (cm)	100	4.41	7.10	3.20	0.68
GMD, Dg (cm)	100	4.99	7.76	3.92	0.62
AMD, Da (cm)	100	5.04	7.80	3.97	0.63
EMD, Dp (cm)	100	5.02	7.77	3.95	0.63
Sphericity, Sp	100	0.91	1.13	0.76	0.05
Surface area (cm^2)	100	79.63	189.23	48.28	21.15
Aspect ratio	100	0.94	1.79	0.71	0.10
Mass (g)	100	74.16	273.66	34.00	29.76
Volume (cm^3)	100	70.80	250.00	30.00	26.88
True density (cm^3)	100	1.05	1.34	0.90	0.09
Bulk density (kg m^{-3})	6	643.25	663.87	610.26	19.31
Peel thickness h (mm)	10	1.06	1.23	0.89	0.13
Packing coefficient, λ	6	0.57	0.59	0.53	0.02
Angle of repose	6	40.67	43.00	38.00	2.51

14.09, 9.89 and 7.22 during drying at 40, 50 and 60°C, respectively. For redness/greenness scale, the initial colour of samples showed positive '*a*' value (23.8), indicating redness (Fig. 3-4). The final '*a*' values varied from 23.8 to 10.34, 4.99 and 3.55 as the air temperature as increased to 40, 50 and 60°C, respectively. This revealed that beetroot loses its redness when dried by hot air. The initial and final

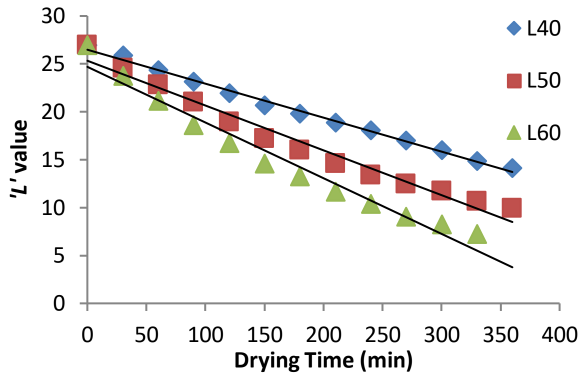

Fig. 1: Kinetic change of '*L*' value as a function of drying time at various air temperatures for zero order model (dots show experimental data and lines show model data)

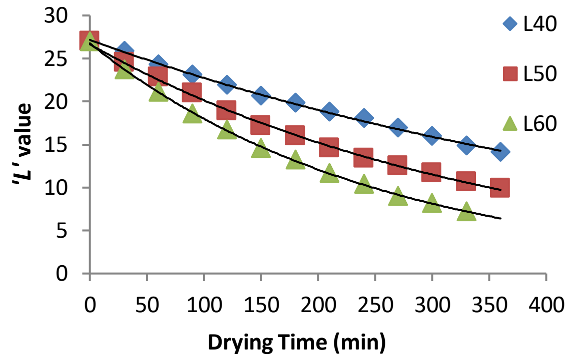

Fig. 2: Kinetic change of '*L*' value as a function of drying time at various air temperatures for first order model

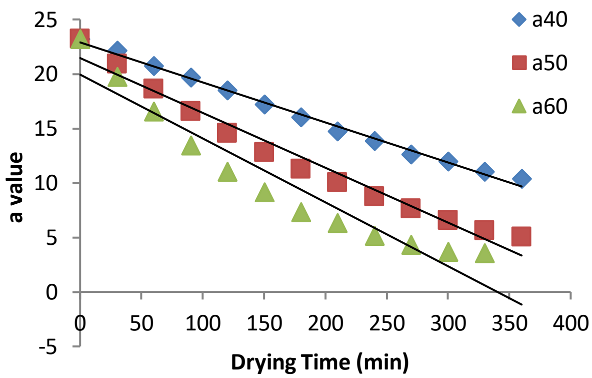

Fig. 3: Kinetic change of '*a*' value as a function of drying time at various air temperatures for zero order model

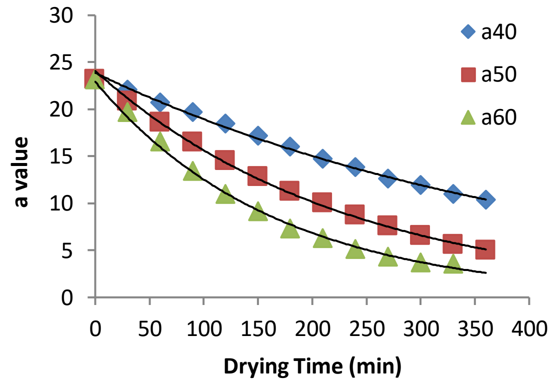

Fig. 4: Kinetic change of '*a*' value as a function of drying time at various air temperatures for 1st order model

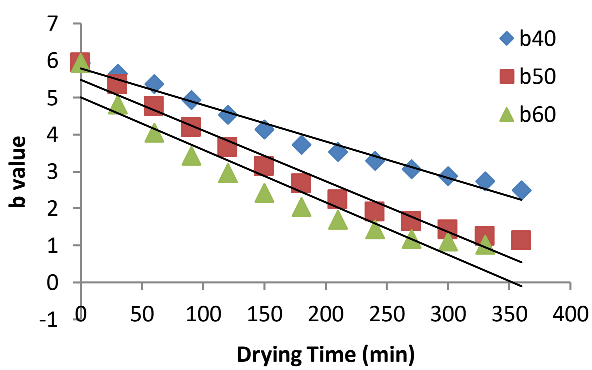

Fig. 5: Kinetic change of '*b*' value as a function of drying time at various air temperatures for zero order model

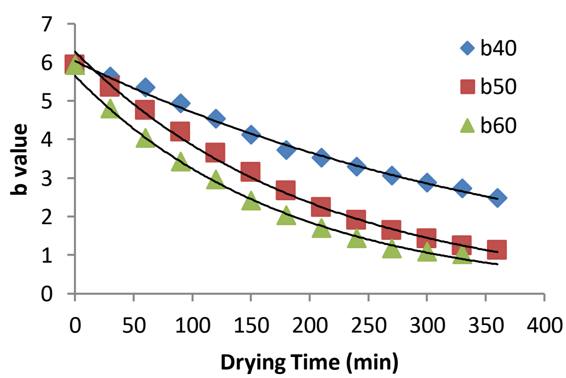

Fig. 6: Kinetic change of '*b*' value as a function of drying time at various air temperatures for first order model

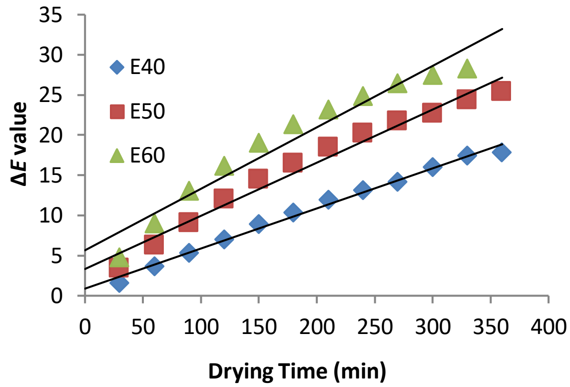

Fig. 7: Kinetic change in total colour change (Δ*E*) as a function of drying time at various air temperatures for zero order model

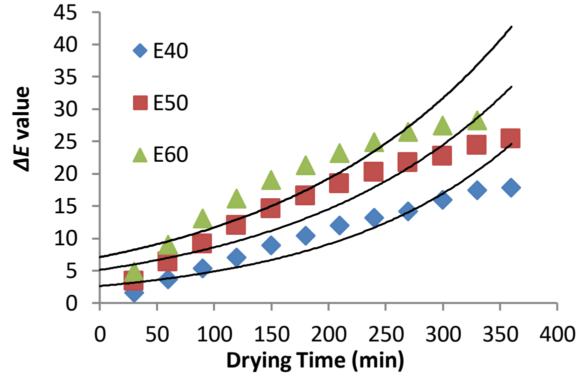

Fig. 8: Kinetic change in total colour change (Δ*E*) as a function of drying time at various air temperatures for first order model

and final '*b*' values changed from 5.93 to 2.48, 1.11 and 1.01 as the air temperature was increased from 40, 50 and 60°C, respectively. It may probably be attributed to the decomposition of carotenoid pigments (Lee and Coates, 1999). As a whole, the total colour change (Δ*E*) of beetroot increased during hot air drying with increase in drying time and reached a value of 17.83, 25.39 and 28.25 as the air temperature was increased to 40, 50 and 60°C, receptively (Fig. 5-6).

For mathematical modeling of colour change of beetroot, zero- and first-order kinetic models were used (Fig. 1-8). It was observed that '*L', 'a'* and '*b'* values were fitted to the first order kinetic model (Fig. 2, 4 and 6). On the other hand, the values of total colour change (Δ*E*) followed a zero-order kinetic model. The results were in agreement with the earlier works revealing that the first-order kinetic model was better for '*L*' and '*b*' values of double-concentrated tomato paste (Barreiro *et al.*, 1997), kiwifruits (Maskan, 2001), pineapple (Chutintrasri and Noomhorm, 2007) and peach puree (Avila and Silva, 1999) and zero-order kinetic model was better for total colour change (Δ*E*) values of kiwifruits (Maskan, 2001), pineapple (Chutintrasri and Noomhorm, 2007) and sunflower seed oil (Maskan, 2003). The estimated kinetic parameters of these models and statistical values of coefficient of determination R^2 are represented in Table 3. The kinetic constant rate of '*L'* increased from 0.002 to 0.004 min^{-1}. For 'a' value from 0.002 to 0.006 min^{-1}, for '*b'* value from 0.002 to 0.006 min^{-1} and for total colour change (Δ*E*) increased from 0.0499 to 0.0765 min^{-1} as the air temperature was increased. This implies that with the increase in air temperature the degradation rate of colour becomes faster as a result of high energy transferred to the inside of food material.

Chroma, Hue angle and browning index

Chroma, Hue angle and browning index were calculated by using Eq. 4-6 and the results are illustrated in Fig. 9-14. The values of chroma and browning index decreased as a function of drying time (Fig. 9, 10, 13 and 14). In case of Hue angle the values of H_{40} and H_{60} decreased according to drying time but the values of H_{60} slightly increased according to drying time. In modeling studies (Fig. 9 and 10), chroma values calculated were accurately fitted to a first-order kinetic model with high value for coefficient of determination R^2 (Table 2).The results were found in agreement with those of Fernando Reyes and Cisneros-Zevallos (2007) for purple- and red-flesh potatoes and it was observed that the first-order kinetic model was better for chroma. In case of browning index, the values were slightly fit in both zero-order and first-order kinetic models (Fig. 13 and 14). The Hue angle value was found poorly fit in zero order and first order kinetic models (Fig. 11 and 12). The kinetic rate constant for chroma, Hue angle and browning index increased as the sample size decreased.

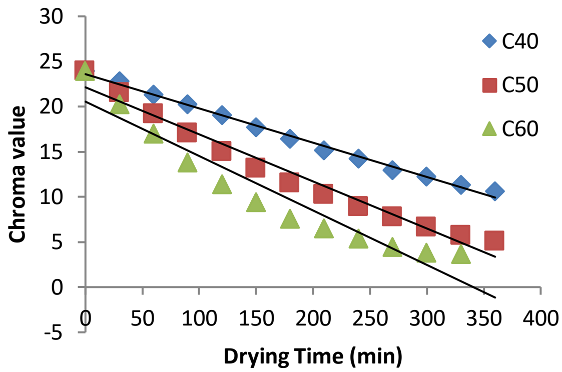

Fig. 9: Kinetics of change of chroma as a function of drying time at various air temperatures for zero order model

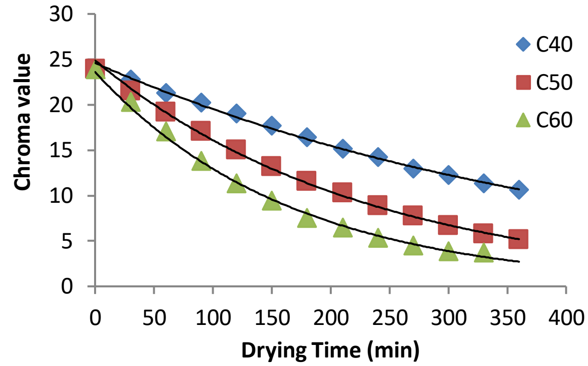

Fig. 10: Kinetics of change of chroma as a function of drying time at various air temperatures for first order model

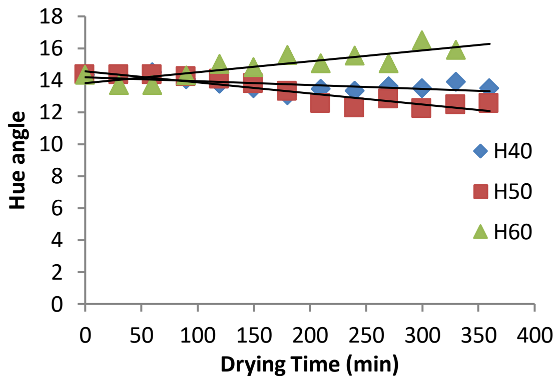

Fig. 11: Kinetics of change of hue angle as a function of drying time at various air temperatures for zero order model

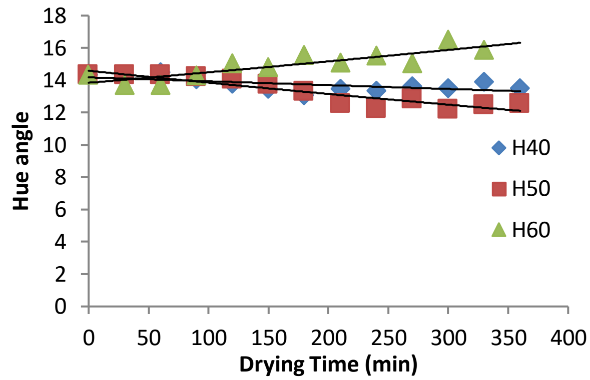

Fig. 12: Kinetics of change of hue angle as a function of drying time at various air temperatures for first order model

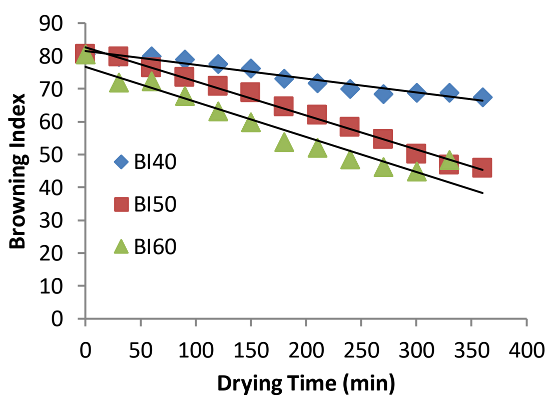

Fig. 13: Kinetics of change of Browning index as a function of drying time at various air temperatures for Zero order model

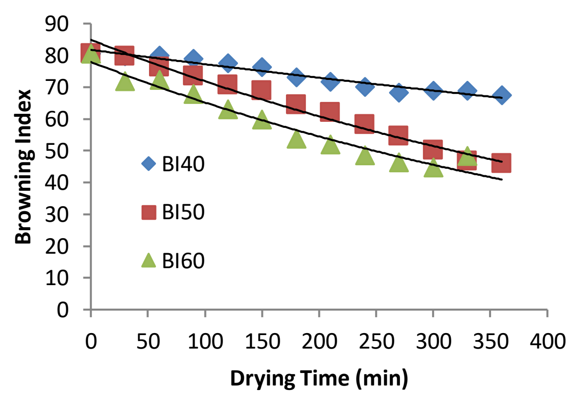

Fig. 14: Kinetics of change of Browning indexas a function of drying time at various air temperatures for first order model

Conclusions: Some physical properties of beetroot may be useful in designing much of the equipment used for harvest and post-harvest processing. Dimensional properties of beetroot i.e. mean length, width and thickness were 5.53, 5.18 and 4.41 cm, respectively; whereas geometric (Dg), equivalent (Dp) and arithmetic mean diameter (Da) of beetroots varied with respective values of 4.99, 5.02 and

Table 2: The estimated kinetic parameters and the statistical values of zero-order and first order models for *L, a, b,* total colour change (Δ*E*), chroma, hue angle and Browning index for various air temperatures

Temperature (°C)	Parameters	Zero-order model			First-order model		
		k (min^{-1})	C_o	R^2	k (min^{-1})	C_o	R^2
40	*L*	0.0581	24.693	0.9663	0.002	27.175	0.9977
	A	0.0367	22.894	0.9944	0.002	23.868	0.9969
	B	0.0099	5.7847	0.9782	0.002	6.0348	0.9957
	Δ*E*	0.0499	0.8809	0.9912	0.0062	2.6147	0.8449
50	*L*	0.03555	26.48	0.9945	0.003	26.643	0.9983
	A	0.0503	21.457	0.9721	0.004	24.081	0.9982
	B	0.0137	5.4777	0.9628	0.005	6.278	0.9971
	Δ*E*	0.0662	3.3265	0.9738	0.0052	5.1129	0.8387
60	*L*	0.0468	25.33	0.9726	0.004	26.765	0.9996
	A	0.0586	19.941	0.9181	0.006	22.932	0.9943
	B	0.0142	5.0031	0.9196	0.006	5.6518	0.9934
	Δ*E*	0.0765	5.6569	0.9474	0.005	7.0842	0.8081
40	Chroma	0.038	23.595	0.9939	0.002	24.6	0.9973
	Hue angle	0.0024	14.185	0.4244	0.0002	14.18	0.4173
	BI	0.042	81.511	0.9487	0.0006	81.738	0.9491
50	Chroma	0.0521	22.138	0.9716	0.004	24.873	0.9983
	Hue angle	0.0069	14.558	0.8471	0.0005	14.587	0.8415
	BI	0.1037	82.635	0.9914	0.002	84.896	0.9768
60	Chroma	0.0603	20.552	0.9183	0.006	23.607	0.9943
	Hue angle	0.0068	13.821	0.7519	0.0005	13.841	0.752
	BI	0.1067	76.697	0.9367	0.002	77.943	0.9464

5.04 cm. The mean true and bulk density of beetroots were 1.05 and 643.25 kg m^{-3}. The packaging coefficient, mass and volume were 0.57, 74.16 g and 70.8 cm^3, respectively. The mean sphericity and surface area were 0.91 and 79.63 cm^2, respectively, while the average aspect ratio, peel thickness and angle of repose were 0.94, 1.06 mm and 40.67°, respectively. The colour change of beetroot slices using *L, a* and *b* system totally explained the real behaviour of beetroot samples undergoing hot air drying. The final values of *L, a, b,* total colour change (Δ*E*), chroma and Hue angle were influenced by hot air drying while Browning index showed that hot air drying caused more brown compounds. The zero order and first order kinetic models used to explain colour change kinetics revealed that *L, a, b* and chroma followed first order kinetics model, while Δ*E* and Hue angle followed zero-order kinetic model. Δ*E* showed increase while *L, a, b,* chroma, Hue angle and Browning index showed decrease when the air temperature was increased.

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