CONVECTIVE DEHYDRATION KINETICS AND QUALITY EVALUATION OF OSMO-CONVECTIVE DRIED BEETROOT CANDY

B. SINGH*[1] and B. SINGH HATHAN[2]

[1]CDL State Institute Of Engineering and Technology, Panniwala Mota, Sirsa, Haryana, India

[2]Sant Longowal Institute Of Engineering and Technology, Longowal, Sangrur, Punjab, India

*Corresponding author. bhupimander@rediffmail.com

ABSTRACT

The Beetroot cubes were osmotically pretreated in 60°Bx of sucrose solution at 55°C osmotic solution temperature for 180 min with fruit to solution ratio 1:4 (w/w). The osmotically dehydrated Beetroot cubes were further dehydrated convectively at different drying air temperatures of 55, 65 and 75°C up to final moisture content of 9±1% (w.b). Among the models investigated, the Page model fitted the experimental data for convective drying of natural and osmosed beetrooot cubes. During convective dehydration, the effective moisture diffusivity of natural samples and osmosed samples at drying air temperatures ranged from 55 to 75°C varied between 8.09917×10^{-9} to 1.45785×10^{-8} $m^2 s^{-1}$ and 1.13388×10^{-8} to 1.61983×10^{-8} $m^2 s^{-1}$ respectively. The activation energy of convective dried natural beetroot cubes was 27.92 kJ mol^{-1} as compared to 16.98 kJ mol^{-1} for osmosed samples. Finally osmo-convectively dried beetroot cubes were coated with sucrose for candy preparation.

Keywords: activation energy, beetroot, convective dehydration, effective diffusivity

1. INTRODUCTION

Beetroot (*Beta vulgaris*) is considered a very important vegetable from the nutritional point of view, which is rich in valuable, active compounds such as carotenoids (DIAS *et al*., 2009), glycine betaine (DE ZWART *et al*., 2003), saponins (ATA-MANOVA *et al*., 1975), betacyanines (PATKAI *et al*., 1997), betanin, polyphenols and flavonoids (VALI *et al*., 2007). Therefore, beetroot ingestion can be considered a factor in cancer prevention (KAPADIA *et al*., 1996). The moisture content of fresh fruits and vegetables is more than 80%, they are classified as highly perishable commodities (ORSAT *et al*., 2006). The moisture content of fruits and vegetables is removed by drying with an aim to preserve and store them for a long period of time by ensuring microbiological safety. Drying is a complex process where heat and mass transfer occurs simultaneously in transient conditions. India is one of the leading producers of fruits and over 20% of the world perishable crops are dried to increase shelf-life and food security (ERTEKIN and YALDIZ, 2004).

The preservation of fruits and vegetables by dehydration should be accomplished in such a manner that the quality effect on the structural configuration of these products is minimized. Among the different methods of food preservation, convective dehydration is the most popular and efficient way to reduce the moisture content and preserve foods. The modes involved in convective drying of foods are heat and mass transfer. Transport of the heat energy flow throughout the medium designated as heat transfer that causes the movement of internal moisture within the foods followed by the movement of water vapor from the food surface is called mass transfer that depends upon external conditions of temperature, air humidity, air flow and area of exposed surface in convective drying. A lot of studies have reported that convective drying is the most popular method applied to reduce the moisture content of fruits and vegetables including beetroot (HENDERSON *et al*., 1961; LEWICIKI, 2006; SHYNKARYK *et al*., 2008). However, this method takes long time and high temperature for drying that affects the nutritive value of products (MARFIL *et al*., 2008).

Product quality notably depends on texture, colour and flavour and they deteriorate with convective dehydration (LENART, 1996). A well-known process to achieve good quality product is freeze drying, but this is an expensive method of food preservation. Therefore, there is a need for simple economic and technically feasible alternative drying processes, which have low capital cost and offer a method that save highly perishable products, making them available to the regions away from production zones. Furthermore, osmotic dehydration is one of such methods that involves the partial removal of water from food, such as fruit or vegetables, by immersion in a hypertonic solution leaving a material that will need shorter drying time than the original food material, thereby, making this process more economical (LENART, 1996; SHI and LEMAGUER, 2002; FASOGBON *et al*., 2013). Osmotic pretreatment can also minimise drying colour losses (RAOULT-WACK *et al*., 1991), as well as reducing nutrient losses (SHI *et al*., 1999). This paper assesses the improvement of the quality of the final product to prevent oxidative browning and the loss of volatile flavoring constituents, reducing the fruit acidity and structural collapse during subsequent air-drying (DIAS *et al*., 2009). It has been reported that when convective drying is conducted between temperatures ranging from 40 to 60°C the moisture curves follow sigmoid shape characteristics of the drying process and shows reduction in drying time with increase in temperature (BARROCA, 2012). Hence, osmo-convective dehydration of beetroot is an interesting alternative for the development of confectionery based functional food with extended shelf life.

One of the most important aspects of drying technology is the modeling of the drying process. The basic principle in modeling is based on a set of mathematical equations that adequately explore the system. The solution of these equations must allow calculation of the process parameters as a function of time at any point in the dryer based only on the primary condition (PREMI *et al.*, 2010). Hence, the use of a simulation model is an important tool for prediction of performance of drying systems. The best model describing the drying characteristics of samples should be chosen as the one with the highest coefficient of determination (R^2), reduced chi-square (χ^2) and RMSE (MADAMBA *et al.*, 1996).

(SHI and LEMAGUER, 2002) calculated effective diffusivity using the slope method but this method gives only a single value of diffusivity for the entire process and therefore does not predict the kinetics of the entire osmotic dehydration process, because the value of diffusivity changes with time and with moisture content of the commodity. Some researchers calculated effective diffusivity by using only first term of the analytical solution of the Fickian model assuming that the effect of terms other than first on the value of diffusivity was non-significant (RASTOGI *et al.*, 1999; SHARMA *et al.*, 2003). Thermodynamically, the activation energy is the ease with which the water molecules pass the energy barrier when migrating within the product (LOPEZ *et al.*, 2009).

In this context, the objective of this work aim to: (i) study the experimental investigation to know the effect of osmotic pre-treatment and drying air temperature on the convective dehydration kinetics and determination of effective moisture diffusivity and activation energy. (ii) develop the preparation of beetroot candy from osmo-convective dried beetroot cubes.

2. MATERIALS AND METHODS

2.1. Sample preparation

Fresh, well graded, beetroot was procured from the local market of Sirsa, Haryana (India). Beetroot was washed properly and cut into 1cm×1cm×1cm size with the help of cutter equipped with a knife moving perpendicularly to a horizontal base. Two types of samples like natural beetroot and osmotic dehydrated beetroot were used for the study of the osmo-convective dehydration kinetics .The initial moisture content of natural beetroot cubes was found to be between 85.71 to 86.29% (w.b.).

2.2. Osmotic dehydration

A known amount (20-25 g approximately) of beetroot cubes were transformed in stainless steel containers containing calculated volume of an osmotic solution of different concentrations at pre-set desired temperature in hot water bath. Temperature of the osmotic solution was maintained by hot water bath agitating at the rate of 75 oscillations per min to reduce the mass transfer resistance at the surface of beetroot and for good mixing (GUPTA *et al.*, 2012).

Optimization of osmotic dehydration process was carried out with the purpose of maximizing water loss, solute gain and quality of the product. The optimum conditions were 60°Bx osmotic solution concentration, 55°C osmotic solution temperature and 180 min process duration at fruit to solution ratio 1:4 (w/w). Following osmotic pre-treatment at optimum conditions, the moisture content of the beetroot cubes reduced to 74.86% (w.b.) and the solid content increased up to 8% designated as osmotic dehydrated beetroot.

2.3. Convective dehydration

The natural and osmosed samples were taken separately in plastic containers before drying and then divided into 175 g portions each. To prepare a shelf stable product, the beetroot cubes was dehydrated up to final moisture content 9±1% (w.b.) at an air temperature of 55, 65 and 75°C and air velocity of 1.6 m s^{-1} (REPPA *et al*., 1999). The dried samples were packed in high-density polyethylene bags after cooling in desiccators and placed at ambient temperature for further analysis. Initial moisture content was determined by the oven-drying method, for the natural and osmosed beetroot samples at a temperature of 135°C for 2 h until constant weight was reached with repetition in order to assure moisture content average values (AOAC, 2000).

3. ENGINEERING ANALYSIS OF DRYING DATA

3.1. Determination of moisture content

The moisture content of the samples during the drying process was calculated according to the following formula.

$$M_t = \frac{W_t - W_d}{W_d} \quad (1)$$

Where,
M_t = Moisture content at time t (g water/ g dm)
W_t = Dry matter at any time t(g).
W_d = dry matter (g).

3.2. Determination of moisture ratio

However, moisture data are used in non-dimensional form so moisture ratio is defined by the following equation:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (2)$$

Where,
MR= Moisture ratio, M_o and M_e Initial moisture content and Equilibrium moisture , g water/ g dry matter content, respectively .M_t, Moisture content at any time t on dry basis (g water/ g dry matter).

3.3. Determination of drying rate

To study the drying behavior at different drying air temperature, moisture content (d.b.) and drying rates were calculated. The drying curves were plotted to observe the effect of process variables. Corresponding to drying curves, the drying rate curves were also plotted (KAR and GUPTA, 2003). The instantaneous drying rate (DR) was calculated from the drying data by estimating the change in moisture content, which occur in each consecutive time interval (dt) and was expressed as a gram of water/gram of dry matter per minutes.

$$DR = -(M_t + d_t - M_t) / d_t \tag{3}$$

Where,
M_t = Moisture content at time t (g water/g dm)
M_t+d_t = Moisture content at time t+ d_t(g water/g dm min).

3.4. Selection of models

The experimental data were fitted using the four models listed in Table 1. In order to find the best suitable model for describing the drying behavior of natural and osmosed beetroot, non-linear regression analysis was used for determination of the constant of each model. The effectiveness of each model used was evaluated critically analyzing coefficient of determination (R^2), reduced chi square (χ^2) and root mean square error (RMSE). The best model describing the convective drying characteristics was chosen based on the higher R^2 value and lower χ^2 and RMSE.

Table 1: Selected convective dehydration models.

Model name with reference	Model
Newton (SINGH *et al.*, 2007)	MR= exp(-Kt)
Henderson and Pebis (GRABOWSKI *et al.*, 2003)	MR= A exp(-Kt)
Page (PAGE, 1949)	MR = exp(-Kt^n)
Wang and Singh (WANG and SINGH, 1978)	MR= 1+At+Bt^2

3.5. Effective moisture diffusivity

An analytical solution of Fick's model of mass diffusion equation for drying biological products in falling period was explained by (CRANK, 1975). When the plot of logarithm of moisture ratio (ln MR) versus drying time is linear, the moisture diffusivity assumes an independent function of moisture content. In this case, the change of moisture content can be described by the following equation (LOPEZ *et al.*, 2009)

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{M_t}{M_o} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)}\exp\left[-\frac{(2n+1)^2\pi^2 D_{eff}\, t}{4L^2}\right] \tag{4}$$

Where,
D_{eff} is the effective moisture diffusivity (m^2/sec) and MR is the moisture ratio. Since the top surface of slices was only exposed to hot air, the length, L, in Eq (4) was the thickness of the slabs. For long drying times; n = 0, then Eq. (4) can be written as;

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{D_{eff}.\pi^2}{4L^2}.t\right) \tag{5}$$

The effective moisture diffusivity was calculated using the method of slopes. When logarithm of MR values v/s drying time were plotted in accordance with Eq. (5), straight lines were obtained at all temperatures and sample thickness was investigated. With the help of linear regression analysis, numerical values of diffusion coefficients were obtained for different drying conditions from the slope of the straight lines.

3.6. Determination of activation energy

Effective diffusivity dependence on drying air temperature was obtained from Arrhenius relationship to calculate the activation energy (LOPEZ *et al.*, 2009).

$$D_{eff} = D_o \exp\left(\frac{-E_a}{R_g(T+273)}\right) \tag{6}$$

Where,
T is temperature (°C), R_g is gas constant having a constant value of 8.314 KJ/mol K, D_o is the pre-exponential factor of Arrhenius Equation, m^2s^{-1}. E_a is the activation energy kJ mol^{-1}.
The above exponential form of Arrhenius equation can be expressed as;

$$\ln D_{eff} = \ln D_o - \frac{E_a}{R_g(T+273)} \tag{7}$$

A plot of ln D_{eff} versus 1/(T+273) gives a straight line of slope E_a/R_g slope and consequently activation energy.

3.7. Preparation of beetroot candy

Osmo-convectively dried beetroot cubes at different temperatures were immersed in sucrose syrup (70°Bx) for candy preparation. Sugar in powder form was crystallized on the surface of beetroot cubes during the cooling process (GUPTA *et al.*, 2012). The resulting beetroot candy was packed in low-density polyethylene bags and kept at room temperature for sensory analysis.

3.8. Sensory evaluation

Organoleptic attributes like color, flavour, taste, texture, and overall acceptability of beetroot candy were determined using a 9-point Hedonic scale with the help of a 10-member consumer panel (WANG *et al.*, 2009). The average scores of all 10 panelists were computed for different characteristics.

3.9. Statistical analysis

All the data obtained from convective drying of osmosed and natural beetroot were analysed to find out statistical parameters like R^2, χ^2 , RMSE and drying constants for different models using statistical package for social sciences (SPSS). Intra-pair significant differences especially for sensory quality attributes were determined using Duncan's tests at 5% level of significance.

4. RESULTS AND DISCUSSION

4.1. Effect of osmotic pre-treatment on convective drying kinetics

Table 2 indicates that, the total convective dehydration time at 55°C of natural beetroot was 690 min, but was 570 min for samples given osmotic pre-treatment with the sucrose solution. Therefore, beetroot samples given osmotic pre-treatment in sucrose solution consequently reduced convective drying time approximately by 120 min when compared with the convective drying of natural beetroot samples (not treated with the sucrose solution) at 55°C air temperature. Similar behaviors have also been observed at 65°C and 75°C drying air temperatures where the convective drying time reduced for the beetroot samples given osmotic pretreatment in sucrose solution by approximately 90 min and 140 min respectively. This might have happened due to leaching of some volatile components of the cellular structure during soaking in osmotic solution. This reduces cell wall resistance and increases drying of beetroot, the results obtained were consistent with data reported by other authors for apricot cubes and melons (RIVA *et al.*, 2004; RODRIGUES and FERNANDES, 2007).

Table 2: Total convective drying time for natural and osmosed dried Beetroot.

Temperature (°C)	Average drying time (min)	
	Natural	Osmosed
55	690	570
65	570	480
75	460	320

4.2. Effect of drying air temperature on drying kinetics

The drying curves for all the drying experiments performed are reported in Figs. 1 and 2. Fig 1 shows the variation of moisture content of osmosed and natural beetroot samples with time for different temperatures. To dry natural and osmosed beetroot sample to final moisture content of 9±1% (w.b.), the drying time at 75 °C was lower as compared to drying time at 65°C and 55°C. Temperature increase cause diffusion coefficient to get higher values, and then drying rate increases. Similar results have been obtained in case of carrot (DIAS I., 2009), garlic (MADAMBA *et al.*, 1996) and eggplant (DOYMAZ and ISMAIL, 2011). It can be seen (Fig. 1) that, the osmosed and natural beetroot did not have any constant rate drying period and complete drying took place during the falling rate period. The absence of a constant rate period was because the product could not provide a constant supply of water for an appreciable period of time for rapid thin-layer drying of the product for initial stages of drying (LAHSANSI *et al.*, 2004; PRAKASH *et al.*, 2004). Drying in the falling rate period showed that internal mass transfer occurred by diffusion. Similar results have been obtained by different authors for drying of vegetables and fruits (DIAS *et al.*, 2009; MADAMBA *et al.*, 1996).

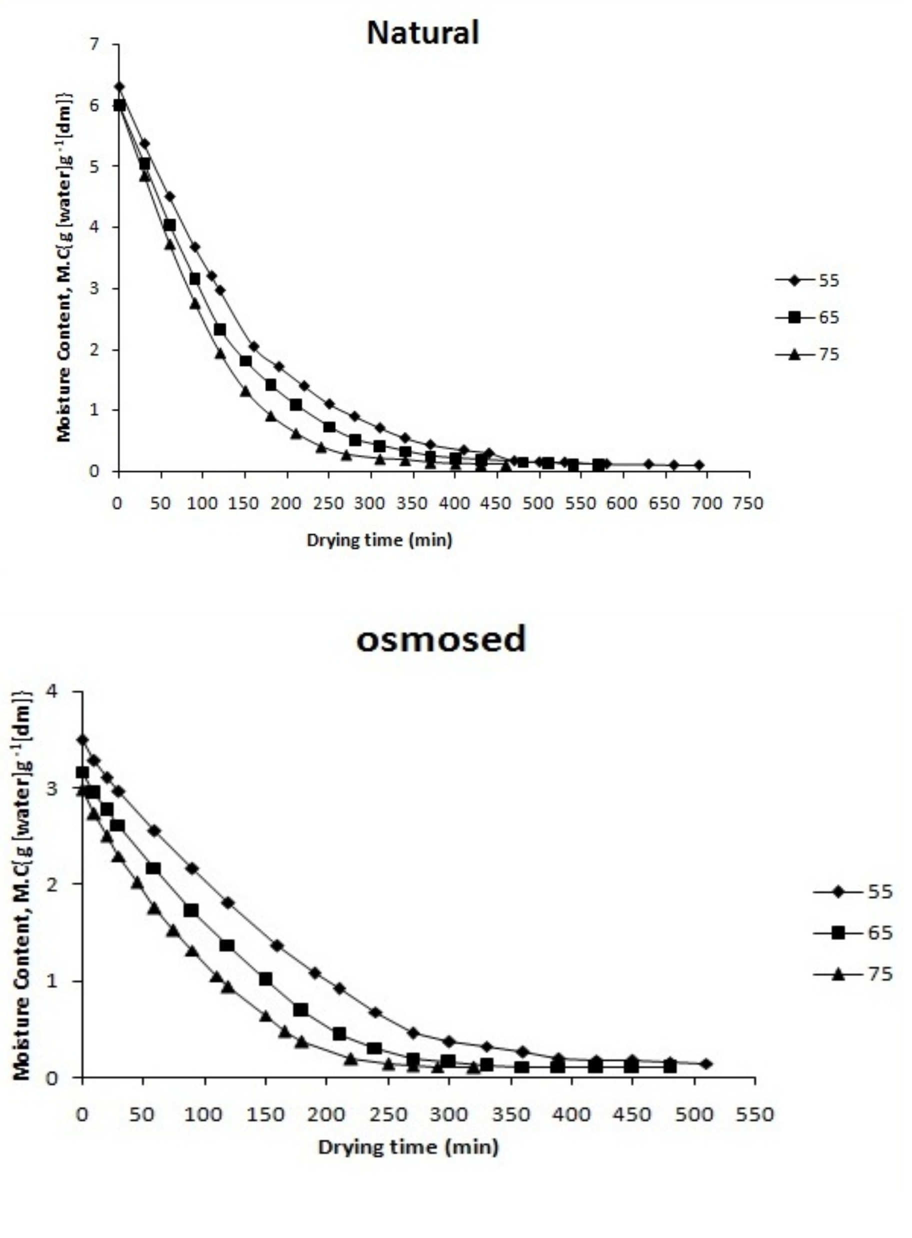

Figure 1: Effect of air temperature on drying behavior of osmosed and natural beetroot cubes at different drying air temperature.

Effect of drying temperatures on a variation of the drying rate with moisture content for osmosed and natural beetroot samples is shown in Fig. 2. Increasing the drying temperature results in an increase of the drying rate and a decrease of the total time of drying. Drying rate later decreased with decreasing moisture for natural and osmotically pre-treated samples under all the conditions of convective dehydration.

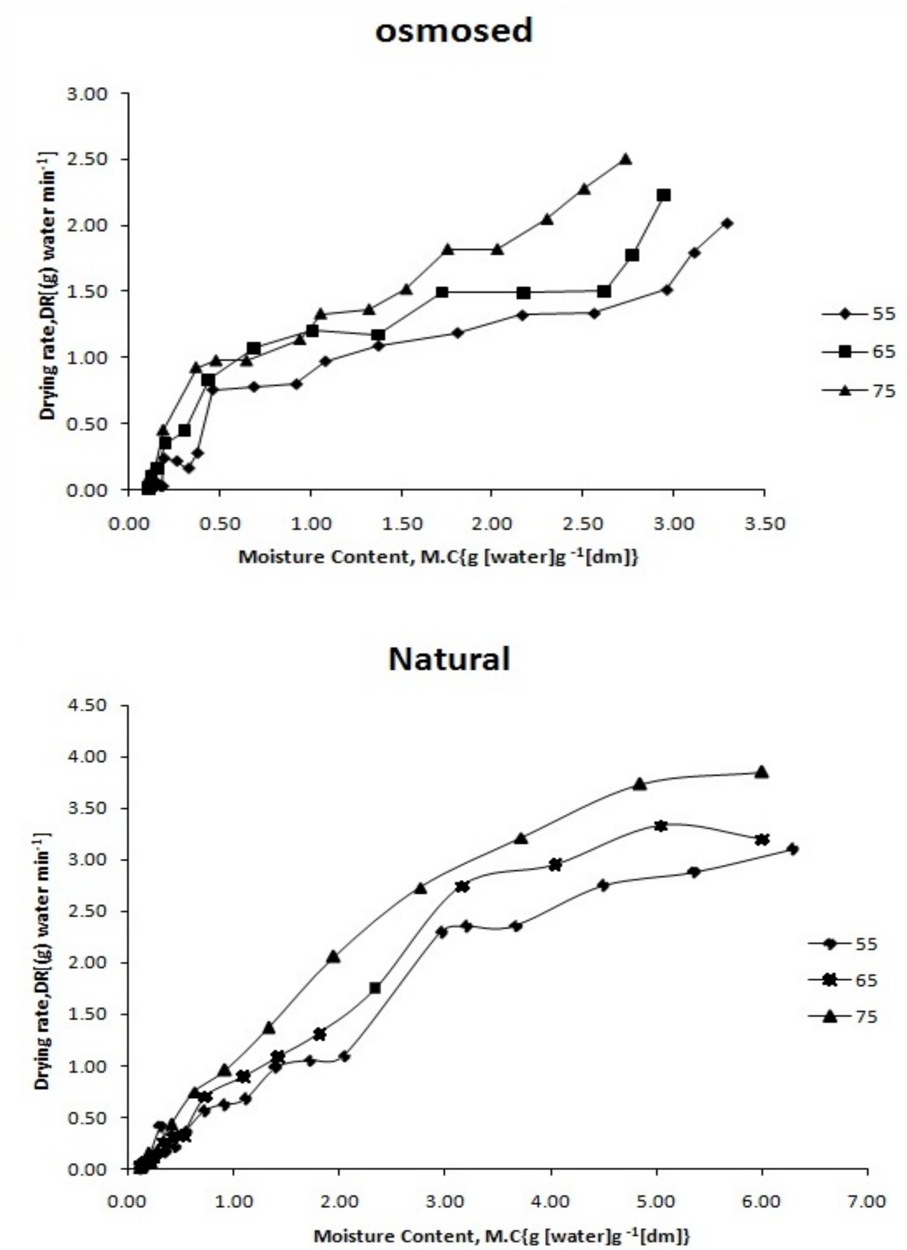

Figure 2: Effect of air temperature on drying behavior of Natural and osmosed beetroot cubes at different drying temperature.

The reason for the reduction of drying rate might be due to the reduction in porosity of the material and also due to shrinkage as the drying process advances. There was a decline in drying rate for both osmosed and natural beetroot. At the end, when moisture content of beetroot cubes neared 1 g [water] g^{-1} [dm], drying rate curves showed very low drying rate. Therefore, a considerably long drying period would be necessary to achieve final moisture content lower than 1 g [water] g^{-1} [dm]. As indicated by drying rate curves in Fig. 2, the migration of moisture to the surface and evaporation (drying) rate from the surface decreased with decreasing moisture in the product. However, closer examination of drying rate for experimental data for values below moisture content of 1 g [water] g^{-1} [dm]

for natural beetroot having higher drying rate compared to osmosed beetroot. This might be due to the resistance offered by solute gain during osmotic pre-treatment.

4.3. Validity of empirical models for convective dehydration

The statistical results with respect to terms of R^2, χ^2, RMSE and drying constants k for Newton, a and k for Henderson-Pabis and k, n for Page and a, b for Wang & Singh models are summarized in Tables 3 and 4, where T is the drying temperature.

Table 3: Statistical results obtained for different convective drying conditions for natural beetroot cubes.

T (^{o}C)	Model	K	Drying coefficients	R^2	RMSE	χ2
55	Newton	0.002	------	0.969	0.06848	0.00498
	Henderson-Pabis	0.002	a=1.106	0.972	0.08645	0.00781
	Page	0.001	n=1.471	0.997	0.05524	0.00293
	Wang and singh	-----	a=-0.002 b=3.97E-07	0.987	0.16862	0.02972
65	Newton	0.003	-------	0.954	0.06888	0.00496
	Henderson-Pabis	0.003	a=1.113	0.973	0.05375	0.00303
	Page	0.001	n=1.467	0.997	0.04860	0.00243
	Wang and Singh	------	a=0.002 b=0.00001	0.986	0.04919	0.00253
75	Newton	0.004	--------	0.983	0.07998	0.00682
	Henderson-Pabis	0.004	a=1.111	0.958	0.06528	0.00453
	Page	0.002	n=1.587	0.997	0.04913	0.00298
	Wang and Singh	------	a=-0.003 b=0.000000115	0.985	0.11529	0.01418

R^2 values greater than 0.95 indicate a good fit, the appropriateness of the selected model is also confirmed by lower value of RMSE and χ^2 (DIAS *et al.*, 2009). Among the models selected for convective drying, the Page model implies an excellent consistency in all the ranges of drying temperature (bold numbers in Tables 3 and 4) and this model may be assumed to represent the drying behavior of Beetroot cubes in a convective dryer within examined range.

4.4. Effective diffusivity for convective dehydration

During convective dehydration, the effective moisture diffusivity of natural samples and osmosed samples at drying air temperatures ranging from 55 to 75°C varied between 8.09917×10^{-9} to 1.45785×10^{-8} m^2s^{-1}, between 1.13388×10^{-8} to 1.61983×10^{-8} m^2s^{-1}, respectively. The results obtained are in good agreement with that reported in the literature (ZOGZAS *et al.*, 1996).

Table 4: Statistical results obtained for different convective drying conditions for Osmosed beetroot cubes.

T (°C)	Model	K	Drying coefficients	R^2	RMSE	χ2
55	Newton	0.003	--------	0.957	0.07316	0.00563
	Henderson-Pabis	0.004	a=1.086	0.972	0.05969	0.00375
	Page	0.002	n=1.415	0.987	0.05543	0.00324
	Wang & Singh	-------	a=-0.002 b=0.0000013	0.979	0.13709	0.01978
65	Newton	0.004		0.961	0.06868	0.00498
	Henderson-Pabis	0.005	a=1.097	0.977	0.05568	0.00327
	Page	0.001	n=1.373	0.986	0.04717	0.00228
	Wang & Singh	-------	a=-0.003 b=0.0000029	0.976	0.09645	0.00982
75	Newton	0.006		0.966	0.06306	0.00428
	Henderson-Pabis	0.007	a=1.062	0.974	0.05904	0.00375
	Page	0.001	n=1.451	0.996	0.05869	0.00347
	Wang & Singh	-----	a=-0.004 b=0.0000047	0.992	0.09136	0.00899

4.5. Activation energy for convective dehydration

The activation energy of convective dried natural Beetroot cubes were 27.92 kJ mol^{-1} compared to 16.98 kJ mol^{-1} for osmosed samples. Activation energy was higher for natural beetroot cubes compared to osmosed beetroot cubes, it may be due to the presence of high initial moisture content of 85% (w.b.) for natural Beetroot samples compared to 74% (w.b.) for pre-osmosed samples. Therefore, more thermal energy would be required to remove greater amounts of water from natural beetroot cubes. Effect of convective drying temperature and time of activation energy were also reported for osmosed and natural samples (REPPA *et al.*, 1999). Similar reports were also found for pears where activation energy was 26.46-31.21 kJ mol^{-1} for pears without osmotic dehydration and 24.34-28.20 kJ mol^{-1} for pears with osmotic dehydration (PARK *et al.*, 2002).

4.6. Sensory analysis for osmo-convective dried beetroot candy

The average score of colour of osmo-convective dried beetroot candy at temperature 65°C was 8.73 compared to temperature at 55°C and 75°C which obtained the score of 8.50 and 8.26 (Table 5) respectively.

Table 5: Effect of convective drying Temperature on sensory quality of Beetroot candy.

Temperature (°C)	Colour	Flavour	Taste	Texture	OA
55	$8.50{\pm}0.10^b$	$8.30{\pm}0.17^a$	$8.26{\pm}0.20^b$	$8.3{\pm}0.17^a$	$8.45{\pm}0.15^b$
65	$8.73{\pm}0.25^a$	$8.53{\pm}0.40^a$	$8.4{\pm}0.15^a$	$8.56{\pm}0.42^a$	$8.59{\pm}0.16^a$
75	$8.26{\pm}0.15^a$	$8.23{\pm}0.05^a$	$8.0{\pm}0.10^a$	$8.0{\pm}0.12^a$	$8.20{\pm}0.05^a$

Means in the same column with different letters as superscripts are significantly different ($p<0.05$).

In case of flavor of osmo-convective dried beetroot candy, the average value at temperature 65°C was higher compared to temperature at 55 and 75°C. Highest score values of 8.4 and 8.56 were awarded to osmo-convective dried beetroot candy at temperature 65°C for its taste and texture respectively. So the overall acceptability score of beetroot candy dried at temperature 65°C was highest over other two temperature treatments. The above results indicated that osmo-convective dried beetroot candy at temp 65°C was the most-preferred candy.

5. CONCLUSIONS

In the present study for preparing a shelf-stable product having final moisture content of 9 ±1% (w.b.), osmotic pre-treatment before convective dehydration of beetroot cubes results in a decrease of the total convective dehydration time. Osmotic pre-treatment also results in increases in drying rate and effective moisture diffusivity and decreasing activation energy during convective dehydration. Among the empirical models applied to the data, the Page model best describes the convective drying characteristics of natural and osmosed cubes. Among osmo-conevctively dried beetroot candies at different temperatures, most preferred candy was obtained at 65°C.

NOMENCLATURE

D_{eff}	effective moisture diffusivity (m^2s^{-1})	M_t	Moisture content at any time t on dry basis (g water/ g dry matter)
E_a	Activation energy	MR	Moisture ratio (Dimensionless)
R^2	Coefficient of determination	M_o	Initial moisture content
t	Time	M_e	Equilibrium moisture content
T	Temperature (^oC)	$\chi 2$	Reduced chi-square
R_G	Gas constant (8.3143KJ $mol^{-1}K^{-1}$)	RMSE	Root mean square error
D_o	pre-exponential factor of Arrhenius equation, m^2s^{-1}		

REFERENCES

AOAC. 2000. "Official Method of Analysis" 17th ed. Association of official Analytical Chemists, Washington, DC.

Atamanova A., Brezhneva T.A., Slivkin A.I., Nikolaevskii V.A., Selemenev V.F. and Crank J. 1975. "Mathematics of diffusion" 2nd Ed. Oxford University Press, London.

Barroca M.J. 2012. Study of drying kinetic of quince. In Proceedings of international conference of agricultural engineering - CIGR - Ag, Valenica, Spain , July 8-12.

Crank J. 1975. "Mathematics of diffusion", 2nd Ed . Oxford University press, London.

DeZwart F.J., Slow S., Payne R.J., Lever M., George P.M., Gerard J.A. and Chambers S.T. 2003. Glycine betaine and glycine betaine analogues in common foods. Food Chem. 83:197-204.

Dias M.G., Camoes M.F.G.F.C. and Oliveira L. 2009. Carotenoids in traditional Portuguese fruits and vegetables. Food Chem. 113:808-815.

Doymaz I. and Ismail. 2011. Drying characteristics of sweet cherry. Food and By Products Process. 89:31-38.

Ertekin C. and Yaldiz O. 2004. Drying of eggplant and selection of a suitable thin layer drying model. J. Food Eng. 63:349-359.

Fasogbon B.M., Gbadamosi S.O. and Taiwo K.A. 2013. Studies on the osmotic dehydration and rehydration characteristics of pineapple slices. Food Process. Technol. 4:4-11.

Grabowski S., Marcotte, M. and Ramaswamy H.S. 2003. Drying of fruits, vegetables, and spices. Ch. 23. In "Handbook of Postharvest Technology:Cereals, Fruits, Vegetables, Tea, and Spices". Chakraverty A, Mujumdar AS, Raghavan GSV, Rawaswamy HS (Ed.), p 653-695. Marcel Dekker Publishing Co., New York.

Gupta R., Singh B. and Shivare U.S. 2012. Optimization of osmo-convective dehydration process for the development of Honey-ginger candy using response surface methodology. Drying Tech. 30:750-759.

Henderson S. M. and Pabis S. 1961. Grain drying theory. II:temperature effects on drying coefficients. J. Agri. Eng. Res. 6:169-174.

Kapadia G.J., Tokuda H., Konoshima T. and Nishino H. 1996. Chemoprevention of lung and skin cancer by *Beta vulgaris* (beet) root extract. Cancer Letters. 100:211-214.

Kar A. and Gupta, D.K. 2003. Air drying of osmosed button mushrooms. J. Food Sci. Technol. 40:23-27.

Lahsasni S., Kouhila M., Mahrouz M. and Jaouhari J. T. 2004. Drying kinetics of prickly pear fruit (*Opuntia ficus indica*). J. Food Eng. 61:173-179.

Lenart A. 1996. Osmotic-convective drying of fruits and vegetables:Technology and application. Drying Technol. 18:951-966.

Lewicki P.P. 2006. Design of hot air drying for better foods. Trends in Food Sci. and Technol. 17:153-163.

Lopez R., Delta A., and Vaca M. 2009. Drying of pricky pear cactus cladodes (*Opuntia ficus indica*) in a forced convection tunnel. Energy converse. Manage. 50:2119-26.

Madamba P. S., Driscoll, R. H. and Buckle K. A. 1996. The thin layer drying characteristics of garlic slices. J. Food Eng. 29:75-97.

Marfil P.H.M., Santos E.M. and Telis V.R.N. 2008. Ascorbic acid degradation kinetics in tomatoes at different drying conditions. LWT-Food Sci. Technol. 41:1642-1647.

Orsat V., Changrue V. and Raghavan G.V. 2006. Microwave drying of fruits and vegetables. Stewart Post-Harvest Rev. 6:4-9.

Page G. 1949. Factors influencing the maximum rates of air drying shelled corn in thin layer. MSc Thesis, Purade University. Lafayette, IN, USA.

Park K. J., Bin A. and Brod F. P. R. 2002. Drying of pear d'Anjou with and without osmotic dehdration. J. Food Eng. 56:97-103.

Patkai G., Barta J. and Varsanyi I. 1997. Decomposition of anticarcinogen factors of the beetroot during juice and nectar production. Cancer Letters. 114:105-106.

Prakash S., Jha S. K. and Datta N. 2004. Performance evaluation of blanched carrots dried by three different driers. J. Food Eng. 62:305-313.

Raoult-Wack A. L., Guilbert S., Le Maguer M. and Andrios G. 1991. Simultaneous water and solute transport in shrinking media:application to dewatering and impregnation soaking process analysis (osmotic dehydration). Drying Technol. 9:589-612.

Rastogi N.K., Eshtiaghi M.N. and Knoor D. 1999. Accelerated mass transfer during osmotic dehydration of high intensity electrical field pulse pretreated carrots. J. Food Sci. 64:1020-1023.

Reppa A., Mandela J., Kostaropoulos, and Saravacos G. D. 1999. Influence of solute temperature and concentration on the combined osmotic and drying. Drying Technol. 17:1449-1458.

Riva M., Campolongo S., Leva A. A., Maestrelli A. and Torreggiani D .2004. Structure- property relationship in osmo-air-dehydrated apricot cubes. Food Res. Intern. 38:533-542.

Rodrigues S. and Fernandes F. A. N. 2007. Dehydration of melons in a ternary system followed by air drying. J. Food Eng. 80:678-687.

Sharma G.P., Prasad S. and Datta A.K. 2003. Drawing kinetics of garlic cloves under convective drawing conditions. J. Food Sci. Technol. 40:45-51.

Shi J, Le Maguer M. 2002. Osmotic dehydration of foods:Mass transfer modeling aspects. Food Rev. Intern. 18:305–35.

Shi J., Le Maguer M., Kakuda Y., Liptay A. and Niekamp F. 1999. Lycopene degradation and isomerization in tomato dehydration. Food Res. Int. 32:15-21.

Shynkaryk M.V., Lebovka N.I. and Vorobiev E. 2008. Pulsed electric fields and temperature effects on drying and rehydration of red beetroot. Drying Technol. 26:695-704.

Singh B., Kumar A. and Gupta A. K. 2007. Study of mass transfer kinetics and effective diffusivity during osmotic dehydration of carrot cubes. J. Food Eng. 79:471-480.

Singh D.B., Kingly A.R.P. and Jain R.K. 2007. Studies on separation techniques of pomegranate arils and their effect on quality of anardana. J. Food Eng. 79:671-674.

Vali L., Stefanovits-Banyai E., Szentmihalyi K., Febel H., Sardi E., Lugasi A., Kocsis I. and Blazovics A. 2007. Liver-protecting effects of table beet (*Beta vulgaris* var. Rubra) during ischemia-reperfusion. Nutrition. 23:172-178.

Wang C. Y. and Singh R. P. 1978. A single layer drying equation for rough rice. St. Joseph, MI:ASAE. ASAE Paper No:78-3001.

Wang R., Zhang M., Mujumdar A.S. and Sun Jin-Cai. 2009. Microwave freeze–drying characteristics and sensory quality of instant vegetable soup. Drying Technol. 2009. 27(9):962-968.

Zogzas N.P., Maroulis, Z.B. and Marinos-Kouris D. 1996. Moisture diffusivity data compilation in food stuffs. Drying Technol. 14:2225-53.

Paper Received February 13, 2015 Accepted June 5, 2015