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Hot air convective dehydration characteristics of *Daucus carota* var. Nantes

Raees-ul Haq^{1*}, Pradyuman Kumar¹ and Kamlesh Prasad¹

Abstract: The present work focuses on experimental and theoretical study of air dehydration kinetics of *Daucus carota* var. Nantes in laboratory scale drying chamber. Steam blanching as a pretreatment was applied prior to dehydration of shreds and the results indicated a gradual decrease in drying time from 2.9 to 5.5% in temperature range of 50–70°C, for steam blanched samples in comparison to untreated carrots. Four different mathematical drying models (Newton, Page, Modified Page and Henderson and Pabis) were evaluated for goodness of fit by comparing their respective R^2 , χ^2 , and RMSE parameters. Comparison of the statistical parameters led to conclusion that Page model showed a better quality of fit and presents dehydration characteristics in better way to obtain drying curves than any other model.

Subjects: Fruit & Vegetables; Preservation; Processing; Product Development

Keywords: carrot; drying; drying kinetics; drying rate; moisture ratio

1. Introduction

Carrot (*Daucus carota*) is important crops of Apiaceae family along with other prominent members of the family include fennel, coriander, parsley, and so on (Cherng, Chiang, & Chiang, 2008). Carrots are among rich and popular sources of carotenoids and phenolics with appreciable amounts of minerals. The edible crop is the primary modification of primary root that has abundant concentration of plant isoprenoid structures or carotenoids. Carrot is the unique root crop that shows the presence of pro vitamin A substances and is grown mainly in temperate regions of the world (Rodriguez-Amaya, 2001). Carrot roots show a greater diversity in root color ranging from ancient black to modern yellow that are used for the development of different food products (Haq & Prasad, 2015). Nantes form of carrot has tapered yellow colored roots popular throughout the world than any other colored root form. These roots have harder crispier texture and richer amounts of bioactive components that make them popular throughout the world (Kaszab, Csima, Lambert-Meretei, & Fekete, 2002).

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PUBLIC INTEREST STATEMENT

The study was conducted to examine the changes taking place during dehydration of carrot. The reduction in moisture content levels was monitored with temperature and overall drying rate at different temperatures was investigated. Understanding these changes is very important for preserving agricultural product for longer periods of time. Drying kinetics when coupled with some chemical analysis is helpful in predicting an effective drying time temperature combination, involving lesser degradation of nutrition parameters within a crop.

Drying is an important processing technique employed in the preservation of different agricultural products since ancient times. The definition of drying has now been overtaken by “dehydration” that involves removal of moisture under controlled aseptic conditions and is a vast subject in itself whose mechanism of action is not fully understood. Drying as a preservation process is associated with enhancing the storage life (Roberts, Kidd, & Padilla-Zakour, 2008) and substantially decreasing volume of the horticulture product that ultimately lowers down transportation, storage, and handling costs. The convective drying aided by air is associated with simultaneous heat and mass transfer (Yilbas, Hussain, & Dincer, 2003) due to (1) moisture diffusion toward the external surface from the solid sample; (2) vapor transfer by convection; and (3) heat transfer by conduction from sample (Maroulis, Kiranoudis, & Marinou-Kouris, 1995). Predicted drying time of agricultural products and generalization of drying kinetics are determined by thin layer drying models, affected by material type, air velocity, and temperature (Erenturk & Erenturk, 2007). Thin layer drying involves dehydration of sample in single layers and this process results in faster moisture removal and consequently lesser nutrient loss.

Although drying kinetics of different horticulture produce is available in the present literature but the same studies related to *Daucus carota* var. Nantes has not been attempted so far. Therefore, present study was focused on dehydration kinetics of carrot shreds and their pretreated form over a temperature range of 50–70°C in a hot air oven.

2. Materials and methods

2.1. Sample preparation

The carrots (*D. carota* var. Nantes) procured from supermarket store were orange colored with longitudinal dimensions of 17–22 cm belonging to maturity group 3rd and 4th (Haq, Singh, Kumar, & Prasad, 2013). The carrots were washed under potable water followed by removing their greeny crowns and adhering root hairs. The roots were stored under refrigeration conditions maintained at 4°C until the start of the experiment. The carrots were grated with a stainless steel shredder (Anjali slicer chipser) forming shreds of 4 × 4 × 20 mm. The moisture content of the shreds was determined in a hot air oven (Association of Official Analytical Chemists, 1990) and parts of these shreds were steam blanched.

2.2. Drying

The samples were dehydrated in a precision hot air oven (Universal Microsil India, Model OVS-3) provided with an airflow value. The blanched as well as unblanched samples were laid onto a wire mesh tray in a single layer and were hanged inside the oven. The samples were taken out at time interval of every 15 min from the oven and recorded for weight on a weighing balance (Ishida Japan) with an accuracy of ±0.001 g. The samples were dehydrated at different temperatures (50, 55, 60, 65 and 70°C) until difference between the two consecutive readings was negligible or until constant weight was achieved. The initial moisture content of the carrots was 88.71% (w.b).

2.3. Mathematical modeling

Drying process was not constant during all experiments of current study and main driving force for dehydration of product is considered to be diffusion (Doymaz, 2004). Drying of a material mainly occurs in during falling rate period of the process during which rate of diffusion is directly proportional to the surface area and concentration gradient. Moisture ratio is the dimensionless quantity used mainly for expressing the dehydration data by plotting MR with drying time (*t*). Mathematically MR is represented expressed as:

$$MR = \frac{M - M_e}{M_i - M_e} \quad (1)$$

where *M*, *M_p*, and *M_e* is moisture content at time *t*, initial moisture content, and equilibrium moisture content (EMC) on dry weight basis, respectively. Equation (1) reduces to *M/M_i* upon neglecting *M_e* as it is a minute term in comparison to *M* and *M_i* (Toğrul & Pehlivan, 2002). Drying rate (DR) of carrot

Table 1. Mathematical models used for studying drying kinetics of carrots

Model	Model equation	References
Newton	$MR = \exp(-k \cdot t)$	Demir, Gunhan, Yagcioglu, and Degirmencioglu (2004), Ayensu (1997)
Page	$MR = \exp(-k \cdot t^2)$	Sarimeseli (2011)
Modified Page	$MR = \exp(-k \cdot t)^2$	Demir, Gunhan, and Yagcioglu (2007), Ceylan, Aktaş, and Doğan (2007)
Henderson and Pabis	$MR = a \cdot \exp(-k \cdot t)$	Henderson and Pabis (1961), Erenturk, Gulaboglu, and Gultekin (2004)

samples was calculated by Equation (2) that involves rate (kg moisture/kg dry matter) of moisture removal with respect to time

$$DR = \frac{M_{(t+dt)} - M_t}{dt} \tag{2}$$

where M_{t+dt} is the moisture content at “t + dt”, M_t is the moisture content at “t”, and dt is difference in time.

Many investigations have used mathematical modeling effectively for drying analysis of various foods (Aghbashlo, Kianmehr, & Samimi-Akhijahani, 2008). Empirical and theoretical models have been widely employed for drying kinetics with some popular ones including Newton, Page, Modified Page, and Henderson and Pabis (Table 1) used in current study to simulate dehydration curves of carrots. Coefficient of determination (R^2), reduced chi square (χ^2), and root mean square error (RMSE) are the statistical parameters used in determining the quality fit of model. The RMSE and χ^2 are calculated by following equations

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - n} \tag{4}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ represent *i*th experimental and predicted MR values, respectively, *N* is the number of experimental data points, and *n* is the number of model constants.

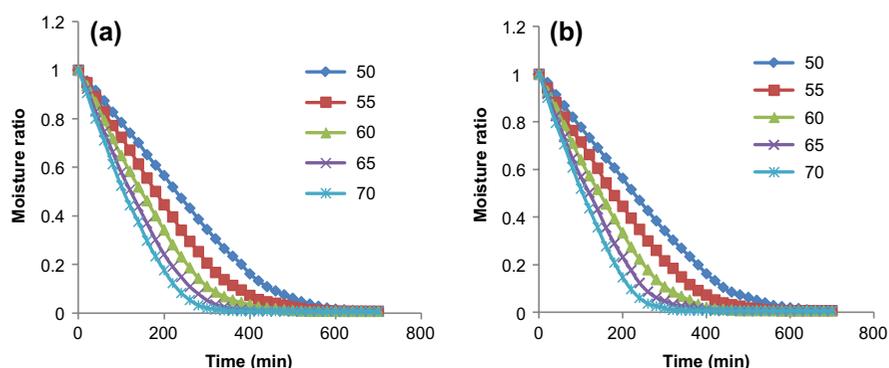
2.4. Statistical analysis

The data was analyzed by Statistica 7.0 (StatSoft Inc., USA) software by nonlinear regression method of Levenberg–Marquardt algorithm. The values of Coefficient of determination (R^2), reduced chi square (χ^2), and root mean square error (RMSE) were calculated to judge predicted values against the experimental ones.

3. Results and discussion

The initial moisture content of the carrot shreds was 7.86 ± 0.025 (kg moisture/kg dry matter). The MR of unblanched and blanched samples is presented in Figure 1. Increase in dehydration temperature decreases the dehydration time in both cases with blanched shreds showing a little bit decrease in dehydration time as compared to its untreated form. Reason for this type of behavior is attributed to blanching that softens the tissue and hence enhances water diffusion rates from the solid sample (Doymaz, 2008; Górnicki & Kaleta, 2007). In both blanched and unblanched carrot shreds drying at higher temperature (70°C) resulted in decrease of time by over 50% or more accurately 53 and 54%, respectively, for former and later. Drying process occurred during the falling rate period during which higher temperatures resulted in reduction of moisture levels to a greater extent that can be correlated to elevated temperatures causing more heat and mass transfer (Aghbashlo, Kianmehr, Arabhosseini, & Nazghelichi, 2011). The time taken by carrot shreds to reach EMC at different

Figure 1. (a) Drying curves-plot of dimensionless moisture ratio vs. drying time for unblanched sample at different drying temperatures. (b) Drying curves-plot of dimensionless moisture ratio vs. drying time for blanched carrot shreds at different drying temperatures.



temperatures is presented in Table 2 that ranges from 6 to 11.66 h. The highest and lowest time as expected was taken by unblanched at 50°C and blanched at 70°C, respectively.

DR of both blanched and unblanched carrot shreds initially increased during the first half an hour of process and there after decreased continuously until its EMC at that temperature was achieved. Higher temperatures in both cases were associated with elevated DRs that resulted in decreasing overall dehydration time by attaining EMC much rapidly (Figure 2). Decrease in dehydration time presented graphically (Figure 3) shows reduction time of around 50% in samples dehydrated at 70°C in comparison to drying at 50°C.

The statistical parameters for evaluating goodness of fit were Coefficient of determination (R^2), reduced chi square (χ^2), and root mean square error (RMSE) shown in Table 3. Highest values of R^2 and lowest χ^2 and RMSE values were the criteria for selecting best model fit (Demir et al., 2004). Among the different models, Page model showed highest values for R^2 and lowest for χ^2 and RMSE

Table 2. Dehydration time (h) of blanched and unblanched carrot shreds to reach to an EMC at different dehydration temperatures

	Time (hours)				
	Temperature (°C)				
	50	55	60	65	70
Unblanched	11.66	10.00	9.00	7.33	6.33
Blanched	11.33	9.67	8.67	7.00	6.00

Figure 2. (a) DR curve of unblanched samples at different temperatures. (b) DR curve of blanched samples at different temperatures.

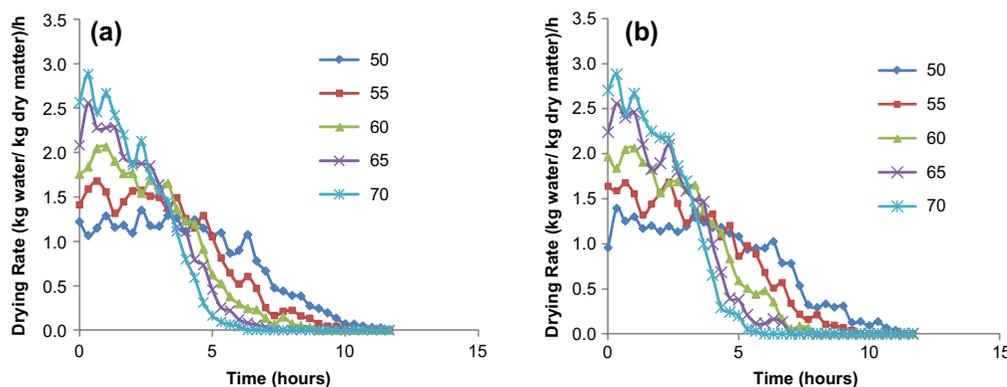


Figure 3. Percent reduction of dehydration time of blanched and unblanched carrots with respect to drying at 50°C.

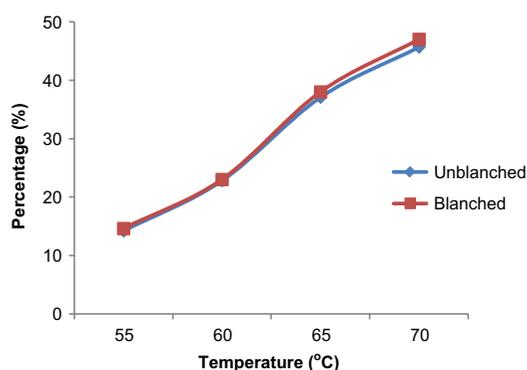


Table 3. Statistical parameters of different models used in determining the equation of best fit

Model	Temperature (°C)	R ²	χ ²	RMSE	R ²	χ ²	RMSE
Newton	50	0.9393	0.0054	0.0747	0.9563	0.0034	0.0600
	55	0.9552	0.0035	0.0607	0.9720	0.0015	0.0419
	60	0.9620	0.0026	0.0531	0.9731	0.0013	0.0392
	65	0.9669	0.0019	0.0465	0.9812	0.0005	0.0275
	70	0.9652	0.0019	0.0467	0.9839	0.0002	0.0229
Page	50	0.9878	0.0002	0.0213	0.9906	0.0002	0.0124
	55	0.9895	0.0000	0.0163	0.9902	0.0002	0.0129
	60	0.9897	0.0001	0.0150	0.9906	0.0002	0.0112
	65	0.9898	0.0001	0.0142	0.9898	0.0002	0.0127
	70	0.9892	0.0001	0.0154	0.9905	0.0002	0.0101
Modified Page	50	0.9393	0.0056	0.0747	0.9563	0.0035	0.0600
	55	0.9552	0.0036	0.0607	0.9720	0.0015	0.0419
	60	0.9620	0.0027	0.0531	0.9731	0.0013	0.0392
	65	0.9669	0.0020	0.0465	0.9812	0.0005	0.0275
	70	0.9652	0.0020	0.0467	0.9839	0.0002	0.0229
Henderson and Pabis	50	0.9552	0.0038	0.0624	0.9681	0.0022	0.0491
	55	0.9657	0.0025	0.0514	0.9775	0.0010	0.0357
	60	0.9707	0.0018	0.0447	0.9784	0.0008	0.0332
	65	0.9739	0.0013	0.0395	0.9831	0.0003	0.0249
	70	0.9718	0.0014	0.0406	0.9856	0.0001	0.0204

(Table 3) indicating its best fit for modeling the drying kinetics of pretreated and untreated carrot shreds. Similar results were shown by Doymaz and Pala (2002), Doymaz (2004), Zielinska and Markowski (2010) and Aghbashlo et al. (2011).

4. Conclusion

Drying kinetics of carrots in dehydration chamber at temperatures range 50–70°C indicated decrease in drying time with blanched samples showing slightly more prominence. The increase in temperature for both blanched and unblanched carrot shreds had a profound effect on reducing drying time by around 46% upon dehydration at 70°C in comparison to 50°C. The changes in moisture content levels during drying at varying temperatures were plotted against time in the form of moisture ratio were fitted to Newton, Page, Modified Page, and Henderson and Pabis model expressions. Among these different models, Page model satisfactorily depicted dehydration characteristics of both blanched and unblanched carrot shreds due higher quality of fit of its statistical parameters.

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Competing interests

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