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MATHEMATICAL MODELING OF HOT AIR DRYING OF FENUGREEK LEAVES (TRIGONELLA FOENUM-GRAECUM) IN CABINET DRYER

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The objective of this study was to develop a model for drying characteristic curve of Fenugreek Leaves in cabinet dryer. Drying experiments were conducted using a constant air velocity 1.1 m/s and two drying air temperature of 40 and 50 °C with four pretreatment conditions (Water Blanched, Water Blanched with potassium metabisuphite + magnesium oxide + sodium bicarbonate, Steam Blanched and Unblanched). The drying rate increased with increased in temperature and decrease with increase in time. Pretreatment (water blanched with chemicals) had a significant role on drying rate and thus reduced the time required for drying. The experimental drying data of fenugreek leaves was applied to seven thin-layer drying models and their performance was evaluated by comparing the coefficient of correlation (R^2), modelling efficiency (EF), reduced chi square (χ^2), Root Mean Square Error (RMSE) and mean relative deviation modulus (PO%) between the observed and predicted moisture ratio. Among all these models, Midilli model was found to be best that describe the drying behavior of fenugreek leaves.

Keywords: Fenugreek leaves, Convective hot air drying, Moisture ratio, Modeling

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum L.*) is herb commonly found in many Asian, European and African countries and locally known as Methi. India is the largest producer of fenugreek in the world. Rajasthan, Gujarat, Uttaranchal, Uttar Pradesh, Maharashtra, Haryana and Punjab are the major fenugreek producing states of India. Its seeds and green leaves are used in food as well as in medicinal application which is an old practice of human history. Leafy vegetables play a very important role in our diet and nutrition since they are a major source of not only raw fiber but also essential nutrients, vitamins and minerals. Fenugreek leaves provides natural food fibre and other nutrients required in human body (Thomas *et al.*, 2011). Experimental and clinical studies have demonstrated beneficial effects of fenugreek in the control of blood glucose, lipids, and platelet aggregation (Khosla *et al.*, 1995) and the defatted part of the plant is said to be responsible for the anti-diabetic action (Ribes *et al.*, 1986).

The seasonal availability together with their high water content which makes leafy vegetables highly perishable, has led to the search for different technologies (refrigeration, drying processes etc) to preserve them and allow availability at anytime. One of the simplest methods to improve the shelf life of leafy vegetables like fenugreek leaves is to reduce their moisture content to such extent that the micro-organism cannot grow (Sobukola *et al.*, 2006). Drying is rated as an important post-harvest process for foods and fruits with respect to high consumption of energy and quality concerns. The final and major purpose is to minimize water activity

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and reduce microbial and chemical reactions. Sun drying is still used for drying fruits and vegetables in spite of considerable drawbacks such as long drying time, pollutions, product deterioration, and unwanted damage. These drawbacks are sufficient enough to substitute industrial and technological trends for drying in order to guarantee demands and preserve the quality (Doymaz, 2007). Moreover, in the last 30 years the need of new technologies allowed to develop several dehydration methods Such as hot air dehydration, osmotic dehydration, microwave dehydration, infrared (IR) dehydration, ultrasonic dewatering, hybrid technologies, etc. The introduction of these technologies in food industries has increased the quality of dried vegetables leading to an exponential increase of the market of these products (Upadhyaya *et al.*, 2012).

During drying processes, the key factor of all traditional and innovative techniques is the mass transfer from vegetable tissues to its surrounding and vice versa. In general, water is the component that moves from vegetable tissues toward the surrounding air but this transfer may occurs through several mechanisms such as capillary flow, diffusion of water due to concentration differences, surface diffusion, vapor diffusion in the pores due to pressure gradient, water vaporization-condensation (Ibarz and Barbosa Canovas, 2003) etc.; moreover, some of these mechanisms may affect each other, making the drying a very complex phenomenon. In general process of drying requires latent heat of vaporization to evaporate moisture, fundamental research with aid of mathematical modeling and numerical simulation provides an extremely powerful and cognitive tool for investigating the complicated physics that evolve during the drying of wet porous materials (Mazumdzar, 1995).

Blanching of vegetable is carried out before drying to inactivate natural enzymes in order to improve color, texture and ultimately the overall acceptability of product (Ahmed *et al.*, 2001). For green vegetable, pretreatment prior to drying can aid the chlorophyll retention during drying. Several studies have been carried out to investigate the effect of pretreatment and hot air temperature on quality of processed vegetables (Kalra, 1990; Kadam *et al.*, 2006; and Kingsly *et al.*, 2007).

An understanding of the fundamental mechanisms, and knowledge of the moisture and temperature distributions within the product, is crucial for process design, quality control, product handling and energy savings (McMinn, 2006). A number of complex theoretical models to describe the heat and mass transfer phenomena during drying are available. Availability of correlations and models, verified by experimental data will enable engineers and operators to provide optimum solutions to aspects of drying operations such as energy use, operating conditions and process control, without undertaking experimental trails on the system (Dincer, 1998). Several thin layer equations available in literature have been successfully used to explain drying of several agricultural products. These include grains (Cao *et al.*, 2004), fruits (Doymaz, 2004), vegetables (Waewsak *et al.*, 2006), leaves and grasses (Sobukola *et al.*, 2006; and Waewsak *et al.*, 2006), Kale leaves (Mwithiga and Olwal, 2005) and green beans (Rosselló *et al.*, 1997). The present study was undertaken with the following objectives:

- To determine the effect of air temperature on the drying behavior of fenugreek leaves in a convective hot air dryer;
- To study the effect of pretreatment on drying characteristics of fenugreek leaves; and
- To select a best model to describe the behavior of fenugreek leaves.

MATERIALS AND METHODS

Fresh fenugreek leaves were procured from local market everyday prior to the experiment. They were washed with tap water and the moisture on the wet sample surface was removed with filter paper. The average value of initial moisture content was found to be 80.89% (w.b.). Fenugreek leaves were pre treated by different blanching treatments, i.e., water blanching, water blanching with chemicals (potassium metabisuphite + magnesium oxide + sodium bicarbonate) and steam blanching. Treated sample were placed over filter paper for 1 minute to absorb excess water.

The drying experiments were conducted at 40 and 50 °C and 1.1 m/s drying velocity using a cabinet dryer (universal hot air oven, tradevel scientific industries), installed in Department of Food Technology, Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India. The drying system was run for about 1 hour to obtain a stable condition before placing samples in the chamber. Digital balance (METTLER, least count 0.001 g) was used for weighing the samples and method recommended by Ranganna (1986) was used for determination of moisture content. The weight of the samples was recorded at different time interval. Initially 5-6 readings were recorded at a time interval of 10-20 minutes, which was then change to 30 minutes and 60 minutes as drying process progressed. Drying was continued till the moisture content reached to the equilibrium moisture content i.e. there was no gain or removal of moisture content later. This method has earlier been used by McMinn (2006). Drying tests were conducted in triplicates at each air temperature and means were reported. Moisture contents of fresh and dried samples were determined using the oven drying method at 105^{0}C till the constant weight (AOAC 1990).

RESULTS AND DISCUSSION

This study was an attempted to describe the drying process of fenugreek leaves by fitting the experimental data on selected drying model for mathematical modeling of it. The suitability of drying models was evaluated on the basis of coefficient of determination (R^2), the reduces chi-square (χ^2), root mean square error (RMSE), modelling efficiency (EF) and mean relative deviation modulus (PO%). A higher value of correlation coefficient (R^2) and modelling efficiency (EF) together with lower value of root mean square error (RMSE), reduced chi square (χ^2) and mean relative deviation modulus (PO%) indicates best fit and checks the adequacy of the fitted equation. These statistical values were calculated as

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{1i}-MR_{2i})^2}{N-n}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(MR_{1i}-MR_{2i})^2}{N}}$$

$$EF = \frac{\sum_{i=1}^{n}(MR_{1i}-MR_{1}mean)^2-\sum_{i=1}^{n}(MR_{1i}-MR_{2i})^2}{\sum_{i=1}^{n}(MR_{1i}-MR_{2i})^2}$$

$$PO\,(\%) = \frac{100}{N}\sum_{i=0}^{n}\left|\frac{(MR_{1i}-MR_{2i})}{MR_{1i}}\right|$$

MR_{1i} is the ith experimental moisture ratio, MR_{2i} is the ith predicted moisture ratio, N is the number of observations, n is number of constant in drying model and MR_{1mean} is the mean value of experimental moisture ratio. And the value of MR moisture ratio is calculated by the help of equilibrium moisture content which is calculated by the method developed by Henderson (1974).

$$MR = \frac{Mt-Me}{Mi-Me}$$

where, M_t is the moisture content at any time t, M_i is the initial moisture content and M_e is the equilibrium moisture content. Mathematical models mentioned in Table 1 were used to simulate the experimental drying curves.

Table 1: Different Models with Their Equation and Reference

S. No.	Model Name	Model Equation	Reference
1	Newton	MR = exp(-kt)	Liu and Bakker-Arkema (1997)
2	Henderson and Pabis	MR = a.exp(-kt)	Henderson and Pabis (1969)
3	Page	$MR = \exp(-kt^n)$	Sharma and Prasad (2001)
4	Overhults	MR = exp{-(kt)?}	Overhults *et al.* (1973)
5	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
6	Midilli	$MR = a.\exp(-kt^n)+bt$	Midilli *et al.* (2002)
7	Logarithemic	MR = a.exp(-kt) + c	Togrul and Pehlivan (2004)

All these equations used the Moisture Ratio (MR) as dependent variable, which related the gradient of the sample moisture content in real time with the initial moisture content and equilibrium moisture content. The experimental data for drying of fenugreek leaves was statistically analyzed with the help of the non-linear regression software package named as SPSS and spread sheet (EXCEL) on personal computer and values of constants used in equations were calculated.

On the basis of experimental results and data analysis the following conclusion were drawn. Figures 1 and 2 show the variation of moisture content of fenugreek leaves with the drying time at 40 °C and 50 °C respectively. It is apparent that the drying rate decreased continuously with the drying time. From Figure it is clearly evident that the drying time decreases with increase in drying air temperature. Hence, experimental results showed that the drying air temperature has a significant effect on the evolution of moisture content. No constant rate drying period was observed in these curves and all drying operations are seen to occur in the falling rate period. These results are in agreement with the earlier observations (Akpinar *et al.*, 2003; Togrul and Pehlivan, 2004; Mwithiga and Olwal, 2005; Sobukola, 2006; and Karva, 2008). The increase in drying rate as temperature of drying air increases is due to increased heat transfer

Figure 1: Changes in Moisture Content with Time During Drying of Untreated and Pre Treated Fenugreek Leaves at 40 °C

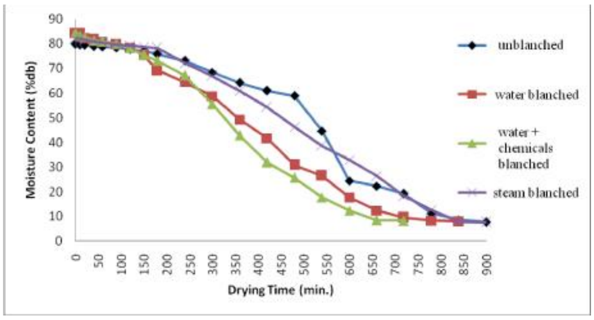

Figure 2: Changes in Moisture Content with Time During Drying of Untreated and Pre Treated Fenugreek Leaves at 50 °C

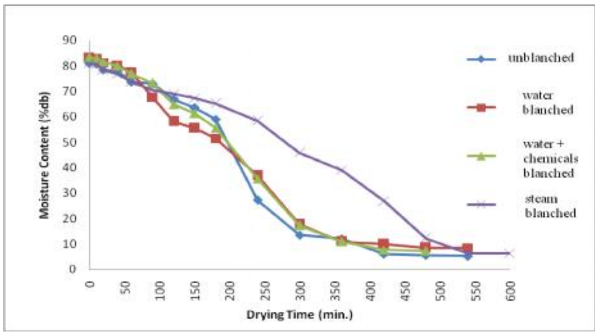

Table 2: Values of Statistical Parameters for Different Drying Models for Drying of Fenugreek Leaves at 40 °C and 50 °C

Model	Temp. (°C)	Statistical Parameters				
		R^2	EF		RMSE	PO (%)
Newton	40	0.74525	1.518508	0.059279	0.23701	115.3615
	50	0.81225	1.471678	0.065233	0.24625	96.56675
Henderson and Pabis	40	0.70975	0.371225	0.25325	0.47625	78.435
	50	0.7995	0.18915	0.21495	0.43098	68.16
Page	40	0.9175	26.85063	0.008356	0.08304	236.3985
	50	0.95875	41.79185	0.005218	0.06542	173.0973
Overhults	40	0.9175	26.8672	0.008354	0.08303	236.3958
	50	0.95875	41.79185	0.005218	0.06542	173.0973
Wang and Singh	40	0.4785	0.781078	0.737395	0.81135	1408.845
	50	0.3955	0.80331	0.991515	0.9154	3298.51
Midilli	40	0.9835	6.990625	0.032975	0.1549	47.76
	50	0.955	18.81985	0.060575	0.16784	77.775
Logrithmic	40	0.70968	-0.7316	0.623003	0.72691	1155.483
	50	0.7995	-0.7556	0.785198	0.79197	2025.915

gradient between the air and the leaves which favors water evaporation from the leaves (Doymaz, 2006). In general, the time required to reduce the moisture ratio to any given level was dependent on the drying conditions, being the higher at 40 °C and the lower at 50 °C. Similar observations have been reported by Simal *et al.* (1996) and also by Ertekin and Yaldiz (2004). It was observed from the figure that the fenugreek leaves blanched in hot water with chemicals took lesser time than the untreated fenugreek leaves and the higher time was taken by the sample that were steam blanched. Earlier study, Kingsly *et al.* supports the results that pretreatments reduce the drying period by increasing the drying rate. Similarly convective drying combined with blanching reported increased drying rate for food products such as apples and peaches by Turhan *et al.* (1997).

Fitting of the Drying Curves

Table 2 presents the results of non-linear regression analysis of seven models at 40 °C and 50 °C. Among these thin-layer drying models, Newton, Henderson and Pabis, Wang and Singh and Logrithmic models obtained very low values of R^2 and thus not considered for comparison.

It is clear from the close examination of the Table 2 that the Page and Overhults model gave a good estimate of 3 statistical parameters i.e. higher value of EF and lower value of RMSE and χ^2 but the average value of mean relative deviation modulus (PO) at 236.4 and 173.1 was much higher than Midilli model. Thus the Page and Overhults model was not found suitable on account of the parameter mean relative deviation modulus (PO) because though Page and Overhults model gave higher value of EF and lower value of RMSE and χ^2, the difference was not much in these three parameters while the value of R^2 is high and the difference was large in PO% in comparison with Midilli model. Thus on the basis of all the five statistical parameters it was found that the Midilli model gave a very good estimate of the drying parameters which fitted well with the experimental drying curves and gave a good set of statistical parameters for fenugreek leaves.

CONCLUSION

In this study, the drying behaviour of fenugreek leaves (*Trigonella foenum-graecum*) was investigated in a cabinet dryer. The drying process at both temperatures of study occurred in the falling rate period, no constant rate period of drying was observed. The drying time reduced with increase in temperature of treatment. The pretreatments, i.e., blanching significantly increase the drying rate and thus decrease time of drying. The drying behaviour was explained using seven thin layer drying models and the results showed that the Midilli model was observed to be most suitable for describing the drying curve of fenugreek leaves for between 40-50 °C air drying temperature and 1.1 m/s air velocity.

DISCLAIMER

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