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Convective drying of fenugreek (*Trigonella foenum graecum* L.) leaves

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Abstract

Dehydration studies on fenugreek leaves were conducted using axial flow convective tray dryer at 50, 60 & 70 °C air temperature & 1m/s air velocity. The time required for drying the fenugreek leaves was observed to decrease with increase in drying air temperature. The time required for drying was recorded as 540, 360 and 240 min for drying air temperature of 50, 60 and 70°C, respectively. The effective moisture diffusivity of fenugreek leaves was found to be increased with increase in air temperature and ranged from 3.25×10^{-12} to 6.49×10^{-12} m^2/s. With increase in drying air temperature, the rehydration ratio and water activity of dried fenugreek leaves was found to increase and decrease, respectively. Maximum rehydration ratio (3.29) and minimum water activity (0.399) was found for samples dried at 70 °C air temperature whereas the quality of product dried at 60°C air temperature was found to be a superior in terms of colour value (L* 65.18; a -24.12 & b -8.17) and sensory characteristics viz., taste (84), colour (77) and overall acceptability (75).

Key words : Convective drying, Drying air temperature, Moisture diffusivity, Rehydration ratio, Water activity,.

Introduction

Fenugreek (*Trigonella foenum graecum* L.) member of Leguminocae family is one of the popular green leafy vegetable in India. Fenugreek is highly seasonal and usually available in plenty during winter season. It is gaining importance, mainly because of being good source of vitamins, minerals and dietary fiber (Karva, 2010; Kalaskar *et al.*, 2012). Fenugreek leaves are mostly used in preparations of various vegetables and food products. Suitable preservation techniques are required for augmenting employment in rural India through proper processing and utilization of this highly perishables leafy vegetables. Drying of green leafy vegetables is simple and economical methods of preservation (Lakshmi and Vimala 2000, Doymaz *et al.*, 2006; Makobo, 2010). Drying of fenugreek leaves creates an avenue for marketing of the produce by reducing the volume and bulk, easy to transport, and adds value in terms of nutritional benefit and economic advantage. In addition to increasing variety in the menu, dehydration of fenugreek leaves reduces wastage, labour and storage space (Rajeswari, *et al.*, 2013).

A number of drying techniques have been developed over years for fruits and vegetables and selection of it for specific products is based upon the physical characteristics and drying behaviour of raw materials as well as the required quality of the finished product. In convective drying, hot air is passed through a moist product for removal of required amount of water. Convection and conduction are the phenomena occurring in the convective drying process (Mujumdar and Menon, 1995). Convective air drying technologies include, hot air tray drying, fluidized bed, and spouted bed drying and these provided similar ratings for colour, anthocyanins content, taste, and rehydration of fruits (Grabowski *et al.*, 2002). But the majority of convective air drying operations are based on hot air drying, where air is heated by the combustion of fossil fuels or using electric heater prior to being forced through the product. According to Mujumdar and Beke, (2003), typical convective dryers account for about 85% of all industrial dryers. Heating of air before drying is the most energy-intensive processes in food processing industries. The conventional thermal drying methods such as hot air-drying result in slow drying rates in the falling rate period of drying (Zhang *et al.*, 2006).

Drying process has been studied for many green leafy vegetables such as solar and cabinet dying of amaranth, curry leaves, gogu and mint leaves (Lakshmi and Vimala, 2000), solar dryer of coriander (Pande *et al.*, 2000), microwave oven drying of mint, coriander, amaranth and shepu leaves (Fathima *et al.*, 2001), cabinet drying of drumstick leaves (Singh *et al.*, 2006) and convective drying of mint leaves (Kadam *et al.*, 2011). Very few literature (Pande *et al.*, 2000, Singh *et al.*, 2006, Karva, 2010) is available on drying of fenugreek leaves but no attempts were made to establish the dehydration kinetics of

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fenugreek leaves. Therefore, study of convective drying of fenugreek leaves was undertaken with specific objective to analyze drying kinetics of fenugreek leaves.

Materials and methods

Sample preparation

Fenugreek plants were procured from the local fruits and vegetables market. Good quality fresh fenugreek leaves were picked manually and washed to remove the adhering dirt/dust prior to dehydration. The moisture content of the fresh and dehydrated fenugreek leaves were determined as described by AOAC, 2000.

Experimental set up

Convective tray dryer (Model no: 12TD, Lab line Gujarat) were used to dry green fenugreek leaves (Fig. 1). The dryer comprised of a drying chamber, fan and heating unit. Drying chamber comprised of an insulated box with a single door opening at front.

Fig 1. Axial flow convective tray dryer

The two sample trays having each size of 340 × 270 mm made of stainless steel were used in the dryer. The bottom of these trays comprises of SS wire mesh which permitted good flow of drying air through the product. The dryer is fitted a continuous weighing scale of 0.01 g least count. The sample trays were hanged with the weighing scale to continuously weigh the sample at a selected time interval without interrupting the system. An axial flow fan with speed regulator for regulation of air velocity is provided on left side of drying chamber. An electric heater of 2.5 kW has been provided on inner right wall of drying chamber for heating of air. Thermostatic controller was used for controlling the temperature of the drying air inside the dryer.

Experimental procedure

Fenugreek leaves samples weighing 200g were taken for conducting all drying experiment at 50, 60 & 70°C air temperatures and spread uniformly on the drying trays placed in drying chamber. The weight of fenugreek leaves sample was recorded for 5 min interval for first half an hour, 10 min interval for next half hour, 30 min interval for next three hours and finally at one-hour intervals until moisture content reached constant value. Data of convective drying of fenugreek were analyzed and regression equations of drying rate were predicted to check the correlations among observed and predicted data. The drying rate of sample was calculated by following equation (Brooker *et al.*, 1974).

$$\text{Drying Rate (R)} = \frac{\text{WML (g)}}{\text{Timeinterval (min)} \times \text{DM (g)}} \qquad \text{...(1)}$$

Where, R = Drying rate, g water/ g dry matter, min and

WML =Weight of moisture loss during the time interval

The effective diffusivity (D_{eff}) was estimated by using Eq (2) which have based on Fick's second law diffusion (Crank, 1975).

$$MR = \left(\frac{M - M_e}{M_0 - M_e}\right) = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{L^2}\right) \qquad \text{...(2)}$$

Where, MR is the moisture ratio, dimensionless,

M = moisture content g water per g dry matter,

M_0 = initial moisture content, g H_2O/g dry matter,

M_e = equilibrium moisture content, g H_2O/g dry matter,

L = characteristic dimension i.e. thickness of leaves (0.0005) m and

t = time elapsed during the drying (s).

Taking logarithm and rearranging the eq. 2 as

$$\ln[MR] = -0.21 - \left(\frac{\pi^2 D_{eff} t}{L^2}\right) \qquad \text{... (3)}$$

Experimental values of the effective diffusivity are typically calculated by plotting experimental drying data in terms of ln (*MR*) versus drying time t. It gives a straight line and the slope of the line used to estimate the moisture diffusivity (eq. 4). This approach was a simplified one and shrinkage of the material was not taken into consideration, *i.e.* thickness of the material L was assumed constant throughout the drying process.

$$\text{Slope} = \frac{\pi^2 D_{eff}}{L^2} \qquad \text{... (4)}$$

Quality Evaluation

Convective dried fenugreek leaves (5g) were put into glass beaker and 200 ml warm water (40°C) was added.

After 1 hour, the excess water was drained off through filter paper (Whatman No. 4) and drained weight of dehydrated materials was taken for determination of rehydration ratio (Ranganna, 2000). Water activity was measured by using digital water activity meter (Model-hygrolab-3). Colour value was measured in three-dimensional scale L*, a* and b* using Hunter Lab Colorimeter, model-NCFLX/DIFF, CFLX-45 (Anantheswaran *et al.*, 1986). Organoleptic parameters *viz.* taste and overall acceptability of dried fenugreek leaves were evaluated by panel of 10 judges. Score sheets describing the quality score (80-100 for excellent, 60-79 for good, 40-59 for fair, 20-39 for poor and 0-19 for very poor) were provided to mark the product according to liking (BIS-6273).

Results and Discussion

The average initial moisture content of the fenugreek was 669.23 per cent (db).

Convective drying behaviour

The effect of drying air temperature with drying time on moisture content of fenugreek leaves during convective drying is presented in Fig. 2.

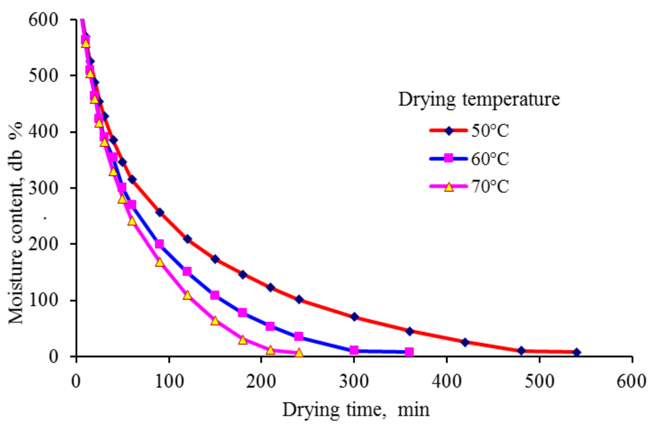

Fig. 2 Variation in moisture content with drying time for convective drying

Fig. 2 shows that the moisture content of fenugreek decreased exponentially with drying time under all drying conditions. The final moisture content was found in the range of 6.92 to 7.72 per cent (db). The drying time required for convective drying of fenugreek at of 50, 60 and 70°C drying air temperature was found to be 540, 360 and 240 min, respectively. The minimum time in drying was observed for higher drying air temperature (70°C) and maximum time was recorded for low drying air temperature (50°C). Fig. 2 shows that as the drying air temperature increased, the time required for drying decreased. The drying data of fenugreek were analysed and regression equations of exponential form were predicted. The values of regression coefficients A and k equations of exponential form are given in Table 1.

Table 1. Regression coefficients of predicted exponential equation

Drying air temperature, °C	Regression coefficient A	Regression coefficient k	Coefficient of determination, R^2
50	578.3	0.0012	0.989
60	618.2	0.010	0.991
70	705.1	0.016	0.985

The good correlation between the drying data was found as the coefficients of determination was more than 0.985 for all drying air temperature. The values of regression coefficients (A and k) of the exponential form varies with variation in drying air temperature (Table 1).

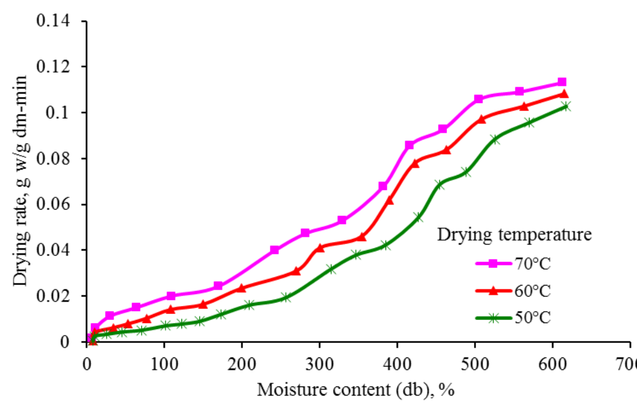

Fig. 3: Variation in drying rate with moisture content for convective drying

Fig 3 clearly indicates that as the moisture content of sample and rate of drying was decreased as drying time proceeds. The rate of drying was observed higher for high drying air temperature. It can be seen from the figures that no constant rate period was found during convective drying of fenugreek and entire drying has taken place in falling rate period. The drying rate curves presented in Fig. 3 and regression equation of third order was fitted in equation of following form.

$$y = a + bx + cx^2 + dx^3$$

Where y is the Drying rate (g water/g dry matter-min), a, b, c, and d are regression coefficients and x is the per cent moisture content (db). The best fit equations with regression coefficients and coefficient of determination values are shown in Table 2.

The values of coefficient of determination were more than 0.989 for all the experiments which shows the good correlation among the predicted and observed data.

Table 2. Predicted equations of drying rate during convective drying

Drying air velocity, m/s	Drying air temperature, °C	Equation predicted	R^2
	50	$y = -3E\text{-}10x^3 + 5E\text{-}07x^2 - 6E\text{-}05x + 0.004$	0.993
1.0	60	$y = -5E\text{-}10x^3 + 7E\text{-}07x^2 - 8E\text{-}05x + 0.006$	0.989
	70	$y = -7E\text{-}10x^3 + 8E\text{-}07x^2 - 5E\text{-}05x + 0.007$	0.992

Effect of air temperature on moisture diffusivity of fenugreek leaves

The variation in ln (MR) with drying time for each case was found to be linear with inverse slope as presented in Fig. 4.

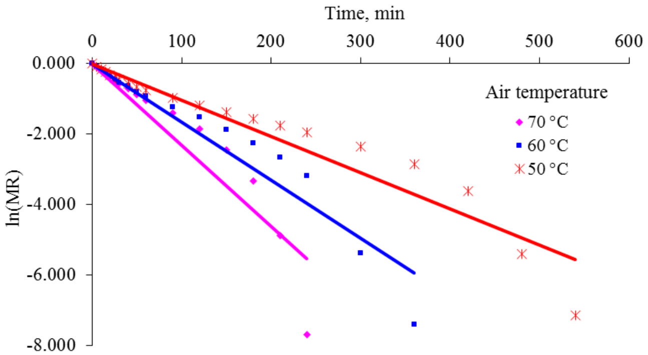

Fig. 4 Variation in ln (MR) with drying time at different air temperature

At all levels straights lines were fitted satisfactory with coefficient of determination $R^2 > 0.90$. The slope became steeper with increase in air temperature. Moisture diffusivity for fenugreek leaves were calculated by using Eq. (4) from the slopes of straight lines curves plotted by ln (MR) verses drying time (Maskan *et al.*, 2002; Doymaz, 2004; Sousa and Marsaioli, 2004) and are presented in Table 3.

It was observed from Table 3 that the moisture diffusivity of fenugreek leaves was found to increase with increase in air temperature. The moisture diffusivity varied in the range of 3.25×10^{-12} to 6.49×10^{-12} m^2/s during convective drying of fenugreek leaves, depending on the air temperature which are in conformity with results of general range of 10^{-08} to $10^{-12} m^2/s$. for drying of food materials (Ganesapillai *et al.*, 2011; Mechlouch *et al.*, 2014).

Quality analysis

Table 3. Effective moisture diffusivity of fenugreek leaves

Air temp. °C	Straight line eq. y = mx + c	Slope (m)	Diffusivity (m^2/s)	R^2
50	y = -0.0002x + 0.056	0.0002	3.25×10^{-12}	0.92
60	y = -0.0003x + 0.178	0.0003	4.87×10^{-12}	0.93
70	y = -0.0004x + 0.322	0.0004	6.49×10^{-12}	0.90

Table 4. Effect of drying air temperature on different quality parameters

Drying air temp, °C	(Colour value)			Water activity	Rehydration ratio
	L*	a	b		
50	61.59	-37.39	-11.76	0.473	2.87
60	65.18	-24.12	-8.17	0.440	3.04
70	57.02	-41.06	-21.06	0.399	3.29

The colour of convective dried fenugreek was measured in terms of L-value (brightness/darkness) and shown in Table 4. Colour (L*, a and b) values of fresh fenugreek leaves were found 79.05, 18.29 and 24.21, respectively. Colour (L*, a and b) values of convective dried fenugreek at 50, 60 and 70°C drying air temperature were found 61.59, -37.39 & -11.76; 65.18, -24.12 & -8.17; 57.02, -41.06 & -21.06, respectively.

The L-values of convectively dried fenugreek was found to increase in drying air temperature from 50 to 60°C, but decreased when drying air temperature was increased from 60 to 70°C due to of elevated temperature. Contrary, the colour (a and b) values of convectively dried fenugreek was found to be decrease in drying air temperature from 50 to 60°C, but increased when drying air temperature was increased from 60 to 70°C. Similar results were quoted in case of the convective drying of apple (Kowalski and Mierzwa, 2013).The fenugreek dried with drying air temperature 60°C was found better colour (L*, a and b) value of 65.18, -24.12 & -8.17, respectively.

The water activity found for all convective dried fenugreek samples are shown in Table 4. Water activity of convective dried fenugreek at 50, 60 and 70°C drying air temperature were found 0.473, 0.440 and 0.399, respectively. It is clear from Table 4 that as air temperature increases, the water activity of dried sample found to be decreased. The lowest (0.396) water activity was found for the fenugreek sample dried at 70°C drying air temperature. This may be due to at higher air temperature, the evaporation rate was higher, influencing the moisture content and consequently water activity of product. From Table 4, the rehydration ratio of convective dried fenugreek at 50, 60 and 70°C drying air temperatures were found 2.87, 3.04 and 3.29, respectively. It cleared that as drying air temperature increases, the rehydration ratio of dried sample found to be increased. Similar trend were observed for the rehydration of of amaranthus leaves (Rajeswari *et al.*, 2011). The highest (3.29) rehydration ratio was found for the fenugreek sample dried at 70°C drying air temperature.

Table 5. Mean sensory score for individual characters

Character	Mean score for product dried at °C		
	50°C	60°C	70°C
Colour	78	84	73
Taste	74	77	72
Overall acceptability	72	75	70

Sensory Analysis

It can be observed from Table 4 that the mean organoleptic score for taste, colour and overall acceptability of the convective dried fenugreek leaves at 50, 60, and 70°C drying air temperature were found 78, 74, 72; 84, 77, 76 and 73, 72, 70, respectively. Mean organoleptic score for taste, colour and overall acceptability convective dried fenugreek leaves at 70°C air temperature was found more than the sample dried at other temperature levels, respectively.

Conclusions

Drying of fenugreek leaves predominately occurred in the falling rate period; hence, the drying process took place by diffusion only. The minimum drying time of 240 min was observed for 70°C temperature with maximum diffusivity of 6.49×10^{-12} m^2/s. The rehydration ratio and water activity of fenugreek leaves was found to increase and decrease with increase in air temperature. Maximum rehydration ratio (3.29) and minimum water activity (0.399) was found for fenugreek leaves dried at 70°C air temperature but the quality of product dried at 60°C air temperature was found to be a superior in terms of colour (L*, a & b) value 65.18, -24.12, -8.17 and sensory characteristics viz., taste (84), colour (77) and overall acceptability (75).

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