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Fluidized bed drying kinetics of fenugreek (*Trigonella foenum graecum* L.) leaves

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Abstract

Fenugreek (*Trigonella foenum graecum* L.) leaves are good source of vitamins, minerals, dietary fiber and mostly used in various vegetables and food preparations. Fluidized bed drying of fenugreek leaves were conducted at 50, 60 & 70°C air temperature & 10 m s^{-1} air velocity to evaluate the drying kinetics. The time taken for drying at 70°C air temperature was found minimum (55 min) as compared to 50°C (90 min) and 60°C (70 min) air temperatures. The effective moisture diffusivity was ranged from 1.78×10^{-11} to 3.55×10^{-11} m^2 s^{-1}. The moisture diffusivity was found to increase with increase air temperature. The rehydration ratio and water activity of fenugreek leaves were found to increase and decrease, respectively with increase in air temperature. Maximum rehydration ratio (3.39) and minimum water activity (0.392) was found for samples dried at 70°C air temperature level but the quality of product dried at 60°C air temperature level was found to be a superior in terms of colour value 71.58, -26.44 & -19.12 and sensory score viz., taste (85), colour (78) and overall acceptability (76).

Key words : Colour value, fenugreek leaves, fluidized bed drying, moisture diffusivity, rehydration ratio, water activity.

Introduction

Fenugreek (*Trigonella foenum graecum* L.) member of Leguminosae family is one of the popular green leafy vegetable in India. Fenugreek is 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 (Singh *et al*., 1997; Lakshmi and Vimala, 2000; Doymaz *et al*., 2006; Makobo, 2010; Kadam *et al*., 2011).

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. Mechanical dryers are rapid and provide uniform, hygienic dried product and reduce losses (Goyal *et al*., 2007). 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). The conventional thermal drying of fenugreek leaves has been studied by several researchers (Pande *et al*., 2000; Singh *et al*., 2006; Karva, 2010) resulted in slow drying rates in the falling rate period of drying.The long drying times at relatively high temperatures during the falling rate periods often lead to undesirable thermal degradation of the finished products and consume more energy and yield low drying efficiency (Alibas *et al*., 2007). Fluid bed drying offers advantages over other methods of drying of particulate materials. Particle fluidization gives easy material transport, high rates of heat exchange at high thermal efficiency while preventing overheating of individual particle. Fluidized bed dryers are widely used in a number of industry sectors to dry finely divided 50–5000 ìm particulate materials. Compared with other drying techniques, fluidized bed drying offers many advantages (Ozbey and Soylemez, 2005).

Several studies on fluidized bed drying characteristics of green leafy vegetables have been reported by researchers for green peas (Hatamipour and Mowla, 2003), celery

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leaves (Jaros and Pabis, 2006), green chilli (Tasirin *et al*., 2007), cabbage (Jin *et al*., 2010), spinach, Swiss chard and leek (Cinar, 2014). Very few literature (Pande *et al*., 2000; Singh *et al*., 2006; Karva, 2010; Pati *et al.,* 2015) is available on drying of fenugreek leaves but no attempts were made to establish the dehydration kinetics of fluidized bed dried fenugreek leaves. Therefore, study of fluidized bed drying of fenugreek leaves was undertaken with specific objective to analyze drying kinetics.

Material 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).

Fluidized bed drying

A tabletop fluidized bed dryer (Make: Sherwood Scientific Ltd. Cambridge, England) was used for drying fenugreek leaves (Fig. 1). The dryer had the provision to vary air velocity as well as drying air temperature. The fluidized bed dryer was simple, compact, portable and easy to operate. The cabinet contained the air distribution system and electrical controls. Air was drawn in through a mesh filter provided at the base of the cabinet and blown by the centrifugal fan over a 2 kW electrical heater. The tube unit consisted of a container with a fine mesh distributor and stainless steel support. A filter bag, which fitted over the top of the tube, retained any particles expelled from the fluidized bed. The fluid bed dryer had PID controller of the range of 0 - 200ºC; which regulated the operation of the heater to maintain the desired preset temperature of the drying air.

The fenugreek samples (100 g) were dried in fluidized bed dryer at 50, 60 & 70°C air temperature and 10 m s^{-1} air velocity. The weight of fenugreek leaves sample was recorded for 5 min intervals using top-pan electronics balance until moisture content reached constant value and average of three replications were used for calculation. The moisture content of the samples at the end of each drying period was calculated according to the loss of mass and the initial moisture content value. The moisture loss data during fluidized bed drying were analyzed and moisture ratios at various time intervals were calculated. The drying rate of sample was calculated by following equation (Brooker *et al.,* 1974).

$$\text{Drying Rate (R)} = \frac{\text{WML (g)}}{\text{Time interval (min)} \times \text{DM (g)}} \quad \ldots(1)$$

Where, R = Drying rate, g water g^{-1} dry matter, min and
WML =Weight of moisture loss during the time interval

Fig 1. Table top fluidized bed dryer

Moisture diffusivity

Effective diffusivity (D_{eff}) of fluidized bed dried fenugreek leaves calculated using following equation as suggested by Mujaffar and Loy (2016) for amaranth leaves.

$$D_{eff} = \frac{\text{Slope} \times 4L^2}{\pi^2} \quad \ldots 2$$

Where, D_{eff} is effective diffusivity of the fenugreek leaves. L is the characteristic dimension *i.e.* half thickness of leaves (0.00025) m and K is the slope of straight line.

The shrinkage of the material was not taken into consideration, *i.e.* thickness of the material L was assumed constant throughout the drying process.

Quality Evaluation

The quality of dried fenugreek samples was evaluated on the basis of rehydration ratio, water activity, colour (L*, a* and b*) values and organoleptic score. Fluidized bed 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 of fluidized bed dried fenugreek leaves 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 fluidized bed 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 liking according to BIS (1971).

Results and discussion

Effect of air temperature on drying time

The moisture content of fenugreek decreased exponentially with the drying time under all drying conditions. The time required for drying the fenugreek up to a moisture content of about 6.31 to 7.54 per cent (db) at 50, 60 & 70°C air temperatures was observed to be 90, 70, and 55 min, respectively. There were about 22.23 and 38.90 % reduction in drying time as power increased from 50 to 60°C and 60 to 70°C air temperature, respectively. The time required for drying was observed to decrease with increase in air temperature (Fig. 2). There was significant reduction in drying time with the increases in air temperature levels. Similar trends have been reported for Fluidized bed drying of spinach, swiss chard and leek (Cinar, 2014). 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. It can be seen from the Table 1 that good correlation exists between the drying data as the coefficients of determination is more than 0.94.

Fig. 3 clearly indicates that 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 figure that no constant rate period was found during fluidized bed 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 0.98 for all the experiments which shows the good correlation among the predicted and observed data.

Effect of air temperature on moisture diffusivity

The variation in ln (MR) with drying time for each case was found to be linear with inverse slope (Fig. 4). The slope of straight lines became steeper and moisture diffusivity was found to increase with increase in air temperature. Table 3 shows that the moisture diffusivity varied from 1.77×10^{-11} to 3.55×10^{-11} m^2 s^{-1} during drying of fenugreek samples for air temperature of 50 to 70°C. The present findings are in conformity with dried vegetables (Senadeera *et al.,* 2005; Jaruk and Roberts, 2006).

The values of effective diffusivity for fluidized bed drying at different air temperature levels along with coefficients of correlation (R^2) are given in Table 3. The ln (MR) and drying time data were observed best fit representing straights line equations with coefficient of determination R^2> 0.90 for all air temperature levels indicating good correlation between the drying parameters.

Quality analysis

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 fluidized bed dried fenugreek at 50, 60 &

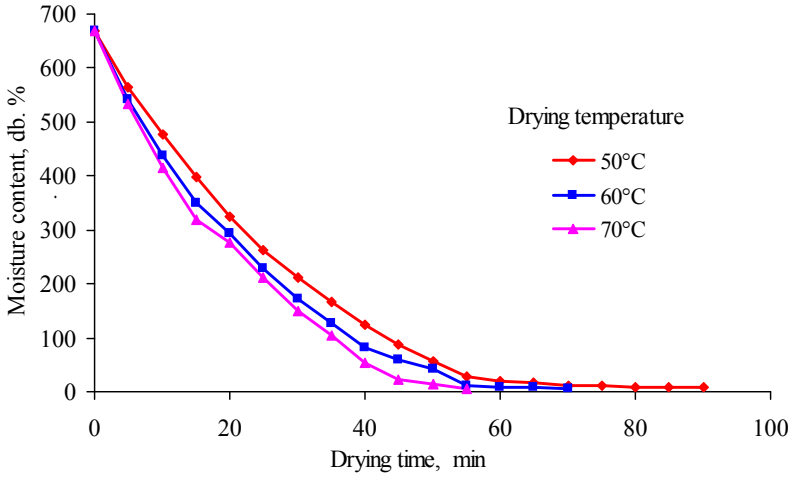

Fig. 2. Variation in moisture content with drying time for fluidized bed drying

Table 1. Regression coefficients of predicted exponential equation

Drying air temperature, °C	Regression coefficient		Coefficient of determination, R^2
	A	k	
50	913	-0.05	0.98
60	1039	-0.07	0.95
70	1062	-0.08	0.94

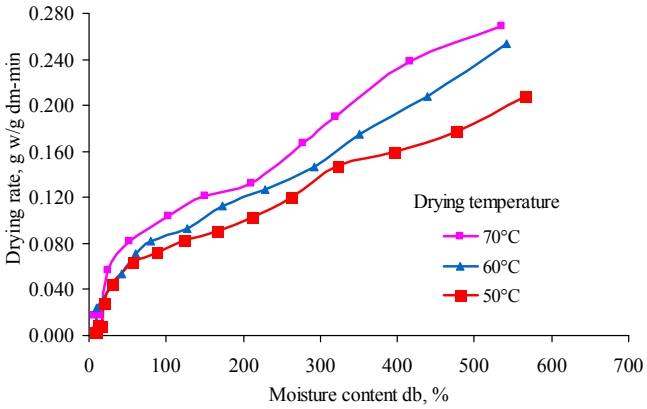

Fig. 3. Variation in drying rate with moisture content for fluidized bed drying

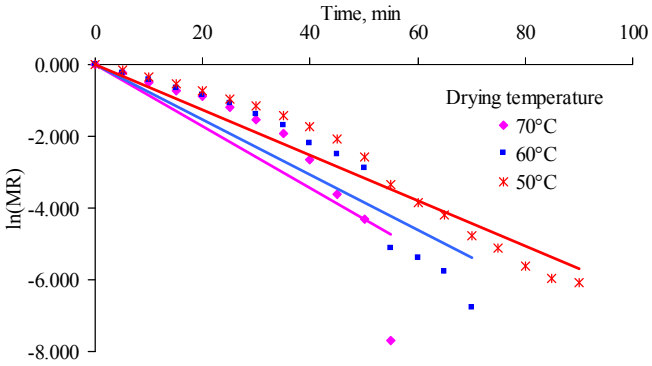

Fig. 4. Variation in ln (MR) with drying time at different air temperature

Table 2. Predicted equations of drying rate during fluidized bed drying

Drying air temperature, °C	Equation predicted	R^2
50	$Y=1E\text{-}09x^3 - 1E\text{-}06x^2 + 0.0001x + 0.023$	0.98
60	$Y=3E\text{-}09x^3 - 2E\text{-}06x^2 + 0.001x + 0.006$	0.99
70	$Y= 2E\text{-}09x^3 - 2E\text{-}06x^2 + 0.0001x + 0.001$	0.98

Table 3. Effective moisture diffusivity of fenugreek leaves during drying

Drying air temperature, °C	Equation of straight line y = mx + c	Slope (m)	Diffusivity ($m^2 s^{-1}$)	R^2
50	y = -0.0007x + 0.671	-0.0007	1.77×10^{-11}	0.97
60	y = -0.0011x + 0.865	-0.0011	2.79×10^{-11}	0.91
70	y = -0.0014x + 0.899	-0.0014	3.55×10^{-11}	0.90

Table 4. Effect of air temperature on different quality parameters

Drying air temperature, °C	(Colour value)			Water activity	Rehydration ratio
	L*	a	b		
50	68.56	-34.34	-24.33	0.423	3.06
60	71.58	-26.44	-19.12	0.404	3.20
70	63.08	-49.20	-28.64	0.392	3.39

Table 5. Mean sensory score for individual characters

Character	Mean score for dried leaves at air temperature		
	50°C	60°C	70°C
Colour	79	85	74
Taste	75	78	73
Overall acceptability	73	76	71

70°C air temperature were found 68.56, -34.34 & -24.33; 71.58, -26.44 & -19.12; 63.08, -49.20 & -28.64, respectively (Table 4).

The L-values of fluidized bed dried fenugreek was found to be increase in air temperature from 50 to 60°C, but decreased when air temperature was increased from 60 to 70°C air temperature due to of elevated temperature. Contrary, the colour (a and b) values of fluidized bed dried fenugreek was found to decrease in air temperature increase from 50 to 60°C, but increased when air temperature was increased from 60 to 70°C. Similar trends were found for fluidized bed drying of curry leaves (Dawn and Naik, 2014). The fenugreek dried with air temperature 60°C was found better colour (L*, a and b) value of 71.58, -26.44 & -19.12, respectively.

Water activity of fluidized bed dried fenugreek leave samples was observed to decrease with increase in air temperature. The water activity of 0.423, 0.404 and 0.392 was determined for air temperature of 50, 60 and 70°C, respectively. The lowest water activity at highest air temperature may be due to higher evaporation rate influencing the moisture content and consequently water activity of product (Kaur and Singh, 2014). Table 4 shows that rehydration ratio for fluidized bed dried fenugreek at 50, 60 and 70°C air temperature which were found 3.06, 3.20 and 3.39, respectively. The rehydration ratio of dried samples was found increased with increase in air temperature. Similar trends were found for the rehydration of fluidized bed dried curry leaves (Dawn and Naik, 2014).

Sensory Analysis

It can be observed from Table 5 that the mean organoleptic score for taste, colour and overall acceptability of the fluidized bed dried fenugreek leaves at 50, 60 and 70°C air temperature were found 79, 75, 73; 85, 78, 76 and 74, 73, 71, respectively. Mean organoleptic score for taste, colour and overall acceptability of fluidized bed dried fenugreek leaves at 60°C air temperature was found more than the sample dried at other power levels, respectively.

Conclusions

Moisture diffusivity and drying time were found to dependent on air temperature used for drying. The minimum drying time of 65 min was observed for 70°C air temperature with maximum moistrue diffusivity of 3.55×10^{-11} m^2 s^{-1}. The rehydration ratio and water activity of fenugreek leaves was found to increase and decrease, respectively with increase in air temperature. Maximum rehydration ratio (3.39) and minimum water activity (0.392) 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 71.58, -26.44 and -19.12 and sensory score viz., taste (85), colour (78) and overall acceptability (76).

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