# Optimization of drying parameters for fenugreek in solar tunnel dryer

MUKESH KUMAR, N.C. SHAHI, J. P. PANDEY and KHAN CHAND

[1-4]*Department of Post Harvest Process and Food Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar-263145 (U. S. Nagar, Uttrakhand)*

**ABSTRACT :** Fenugreek (*Trignomella foenumgraceum*), is highly perishable and one of the most important leafy vegetables widely used for culinary purpose. Drying increases the shelf life of product while mechanical drying involves higher cost of drying and open sun drying deteriorates the quality. Thus, the need for an intermediate level technology was realized and drying was carried out in developed solar tunnel dryer. The independent variables were taken as temperature (45-65°C), chimney height (0.7-1.1 m), product size (2-10 cm) and pre-treatment (0-10%). Response surface methodology was used to design the experiments. The fenugreek was dried from initial moisture content 746.03 to 1330.62% (db) to final moisture content 4.036-5.397% (db). Total drying time ranged from 230 to 420 min and considerably reduced by 67% in STD as compared to sun drying. To understand the physics of drying, the exponential model was found best than other models because higher $R^2$ and least SEE. Ascorbic acid and carotene were determined in the range of 22-38.08 mg/100g and 58.51-55.89 mg/100g. For good quality of dried product, the temperature, chimney height, product size and pre-treatment were found to be 51.75°C, 0.838 m, 4 cm and 4.325%.

**Key words:** Ascorbic acid, carotene, colour, fenugreek

Fenugreek commonly known as *Green Hay* and *Methi*, is an herbaceous plant of the *leguminous* family and is native to Western Asia and also commonly found in European and African continent. India is one of the largest producers of fenugreek in the world. Rajasthan, Gujarat, Uttarakhand, Uttar Pradesh, Haryana, Maharashtra and Punjab are the major fenugreek producer states of India. It is basic ingredient for its appetizing fragrance and basic ingredient in many culinary preparations. Fenugreek leaves besides being a gourmet's delight are also used for treatment of a variety of health problem. It contains many nutrients and other active ingredients as protein, vitamin C, niacin, potassium, alkaloids, lysine and L-tryptophan as well as steroidal saponins which are beneficial for human health (Hemavathy and Prabhakar, 1989). It has been used in treating colic flatulence, dysentery, diarrhoea, dyspepsia with loss of appetite, chronic cough, enlargement of liver and spleen (Abdul barry *et al.*, 1997).

Solar drying is a continuous process where moisture content, air and product temperature change simultaneously along the two basic inputs to the system i.e. the solar radiation and the ambient temperature. The drying rate is affected by ambient climatic conditions which include temperature, relative humidity, sunshine hours, available solar radiation, wind velocity, frequency and duration of rain showers during the drying period.

The solar poly house tunnel dryer developed in the department of Post Harvest Process and Food Engg. G.B. Pant Univ. of Agri. & Technology, Pantnagar, is one promising option for drying high moisture content fruits and vegetables. The advantage of solar poly house tunnel dryer is its relatively cheaper cost of construction and operation. Few research worker Sawant *et al*. (2008); Pandhre *et al*. (2011) had worked on sun drying and compare the quality parameters on infra-red and tray dryer. No work has been done in drying of fenugreek on solar tunnel dryer. Therefore, an attempt was made to dry fenugreek vegetables in solar tunnel dryer. The specific objective of the work was:To study the drying characteristics of fenugreek in solar poly house tunnel dryer.

## MATERIALS AND METHODS

### *Experimental design*

On the basis of earlier work done by various research workers (Negi and Roy, 2001; Sagar, *et al*., 2006; Padavi, 2009) the temperature, chimney height (to check the effect of air flow rate), pre-treatment and product size were selected as processing parameters for dehydration of fenugreek and to optimize the drying parameters. The five levels of each variable were taken. The coded and actual values are given in Table 1. Response surface

**Table 1: Levels of independent variables in coded and actual form for the experiment**

| Independent Variables | Code | Coded level | | | | |
|---|---|---|---|---|---|---|
| | | -2 | -1 | 0 | +1 | +2 |
| Temperature, °C | $X_1$ | 45 | 50 | 55 | 60 | 65 |
| Chimney height, m | $X_2$ | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 |
| Pre-treatment, % | $X_3$ | 0 | 2.5 | 5.0 | 7.5 | 10.0 |
| Product size, cm | $X_4$ | 2 | 4 | 6 | 8 | 10 |
| Constant parameter during drying | | | | | | |
| Shade net, % | | | 50 | | | |
| Loading density, kg/m$^2$ | | | 2 | | | |

methodology of which central composite rotatable design was used without affecting the accuracy of result and to decide interactive effects of variables on the responses (Myers, 1971).

***Experimental procedure***

Fresh and matured fenugreek procured from a Vegetable Research Centre of Pantnagar, Uttrakhand and thoroughly cleaned before manual trimming. The roots were removed from fenugreek foliage followed by cleaning in cold water to remove soil and dust particles. Washed fenugreek foliage's were weighed using digital balance for fixed loading density of 2 kg/m$^2$ and placed in a perforated tray of size of 0.22 X 0.23 m$^2$ giving a sample size of 100 g respectively. Prior to drying the samples was treated with sodium meta bisulphate solution for 3 min with the sample to solution ratio of 1:5. Treated sample was placed over a perforated tray to drain surface water before loading into the tray.

***Drying in solar tunnel dryer***

Samples of treated fenugreek were spread uniformly in a single layer on tray of STD. Temperature of the drying air is fixed during the experiment by using auxiliary heating system. For each of the experiment the dryer was loaded to its full capacity. Weight loss of the sample were measured with electronic balance and recorded with an interval of 15 min for first hour of observation the time interval increased to 30 min and later stages of drying decreased to 10 min interval. The initial moisture content of fenugreek was determined by hot air oven method. The drying of fenugreek foliage, to bring the moisture at safe level of 4 to 6 % (db) took 6 to 9 hr. When the desired moisture content was not achieved within 1 day experiment then fenugreek was kept in closed condition and the drying was continued on following day. The dried fenugreek leaves were packed in polythene bags of 200 gauge and stored at room temperature for further analysis. The process chart for drying of fenugreek is shown in Fig1.

***Assessment of quality***

*Ascorbic acid*

Ascorbic acid of fresh and dried sample was determined by 2, 6- dichlorophenol- indophenols visual titration method (Ranganna, 1986).The ascorbic acid content of the sample calculated using the formula

$$\left(\begin{array}{c}\text{Ascorbic acid@}\\ \text{(mg/100g)}\end{array}\right) = \frac{\text{(Titre X Dye factor X volume made up) X 100}}{\left(\begin{array}{c}\text{A Liquot of extract}\\ \text{taken for estimation}\end{array}\right) \text{X} \left(\begin{array}{c}\text{Volume of sample}\\ \text{taken for estimation}\end{array}\right)} \quad (1)$$

***Chlorophyll and Carotene***

Total chlorophyll was measured following the method describe by (Lichtenthaler and Wellburn, 1985). Chlorophyll pigment was extracted from 1 g dry matter in 100% acetone and was determined using spectral analysis (Beckman) by measuring the absorbance at 470, 645, 662 and 666 nm.

$$C_a = 11.75A_{666} - 2.350A_{645} \quad (2)$$

$$C_b = 18.61A_{645} - 3.960A_{662} \quad (3)$$

$$C_X + C = \frac{[1000A_{470} - 2.270C_a - 81.4C_b]}{227} \quad (4)$$

Where, $A_x$ = absorbance at specific wave length, X, $C_a$ = chlorophyll-a (mg/g), $C_b$ = chlorophyll-b (mg/g) and $C_x$ + C = carotene (mg/g)

***Colour***

The digital photographs of each dried sample were analyzed using Adobe Photoshop 7.0 software. The L, a, b (Lightness or darkness of the sample, from green to red, from blue to yellow) value for each dried sample were obtained at lab colour mode Kashaninejad and Tabil, (2004).

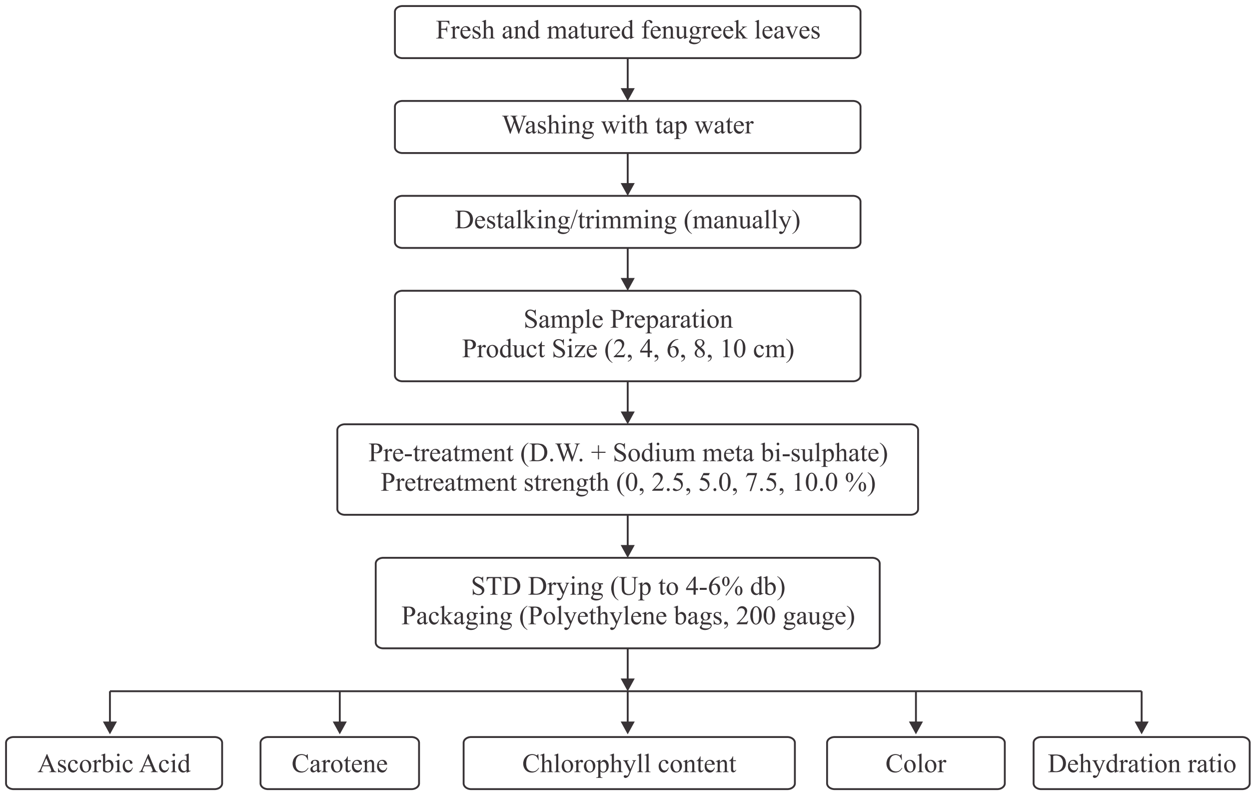


**Fig.1.** Flow chart for drying process of fenugreek

***Dehydration ratio***

Dehydration ratio was calculated by taking the weights of fresh and dried sample (Pawar *et al.*, 2000; Sagar *et al.,* 2001).

$$\text{Dehydration ratio} = \frac{W_B}{W_D} \tag{5}$$

Where, $W_B$ = weight of fenugreek before drying, (gm) and $W_D$ = weight of fenugreek after drying, (gm)

***Drying data analysis***

*Equilibrium moisture content*

Equilibrium moisture content was required for calculations of Moisture Ratio (MR). It was determined using a method, in which last three moisture content readings of drying experiment were considered. Following equation was used to determine the equilibrium moisture content (Mujumdar, 1995).

$$M_e = \frac{M_1 \times M_3 - (M_2)^2}{M_1 + M_3 - 2M_2} \tag{6}$$

*Moisture ratio and drying rate*

Moisture ratio (MR) is defined

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{7}$$

Where, M = Average moisture content (% db) at time t (min) during drying, $M_o$ = Moisture content (% db) at the initiation of drying i.e. at zero time and $M_e$ = Equilibrium moisture content (% db)

*Drying rate*

It is defined as,

$$\frac{DM}{DT} = \frac{M_2 - M_1}{\Delta t} \tag{8}$$

Where, $\Delta t$ = difference in time

***Empirical modeling***

To understand the drying behaviour, there is a need to develop mathematical models to predict the drying condition. Several attempts have been made to develop analytical and empirical models. The moisture ratio (MR) curves explain drying behaviour better than that of moisture content curves. MR data were fitted into Page's, generalized exponential and logarithmic model.

2.9.1 Page Mode l (Brooker *et al*., 1974)

$$MR = \frac{M - M_e}{M_0 - M_e} = e^{(-Kt^n)} \quad (9)$$

Where, t = Drying time, min and K, n = constants of page's equation

*2.9.2 Generalized Exponential Model* by Pande *et al.,* (2000)

$$MR = \frac{M - M_e}{M_0 - M_e} = A \times e^{(-Kt)} \quad (10)$$

Where K, A = Drying constants

*2.9.3 Logarithmic Model* by Mishra, (1991)

$$MR = \frac{M - M_e}{M_0 - M_e} = a + b \ 1n\ (t) \quad (11)$$

Where a, b – Drying constants

## RESULTS AND DISCUSSION

***Properties of fresh fenugreek***

The moisture content of fresh and dried fenugreek foliage ranged between 88.18% and 93.01% with an average of 90.10±2.91% (wb). Fenugreek foliage was grouped under highly perishable vegetable due to high moisture content. Preparatory losses of the fenugreek were measured and found that about 27% weight of fenugreek was lost due to removal of root, soil and foreign material, infected leaves and leaves with mechanical injuries. The remaining 73% fenugreek was used for the experimental work. Chlorophyll-a, chlorophyll-b, ascorbic acid and carotene were determined as 334.62 mg/100g, 128.91 mg/100g, 51.03 mg/100g and 67.73 mg/100g respectively.

***Drying Characteristics***

*Moisture content*

The moisture content of fresh fenugreek varied from 746.03 to 1330.62% (db) whereas the final moisture content after drying varied from 4.036 to 5.397% (db). The interrelationship shows nonlinear decrease of moisture content with drying time. The rate of moisture decrease was very rapid at the initial stage, then it reduced considerably and finally it became constant and close to zero. The moisture content of fenugreek decreased with time for all conditions. However, as expected the drying time varied with the drying conditions. For entire experiments it ranged from 230 to 420 min depending on experimental and drying conditions. The open sun drying takes 15-16 hr for drying of fenugreek to the final moisture content of about 5%. Thus, the drying time was reduced considerably to open sun drying as compared to sun drying.

The moisture ratio was determined by calculating equilibrium moisture content (Me) using the Eqn 6 and 7. The interpretation of moisture ratio with drying time for all experiments of dried fenugreek is shown in Fig 3. The moisture ratio data were tried to fit into various mathematical models, viz., Page's, generalized exponential and logarithmic model and best predicting model for moisture ratio during fenugreek dehydration was selected. The coefficient of determination, $R^2$, varied between 0.543 and 0.710 in case of Page model while that of generalized exponential model 0.930-0.998 and 0.881-0.901 in case of logarithmic model. It also shows that SEE varied from 0.705-1.241, 0.881-0.901 and for Page model, generalized exponential and logarithmic model respectively. On the basis of higher $R^2$ and less variation in standard error, it was concluded that exponential model described the experimental data satisfactorily as compared to other models.

*Drying rate*

The rate of drying as expected decreased continuously with the increase in time, being faster at higher temperatures. Lot of variation was observed in drying rate due to changing conditions in STD with time due to ambient air and solar radiation. The decrease in drying rate with the period of drying was non-linear shown in Fig. 2. The drying process of a high moisture food consists of two drying rate periods: constant rate and falling rate period (Brooker *et al.,* 1974). But in the case of fenugreek dehydration, the constant rate drying was not observed in any set of experimental data. The complete drying took place in falling rate period.

***Optimization of drying parameters for fenugreek***

Optimization is a process of making compromises between responses, to achieve a common target. Numerical optimization was carried out using Design–Expert 8.0.7.1 software. The goal was fixed to be in the range for ascorbic acid, carotene, chlorophyll-a,

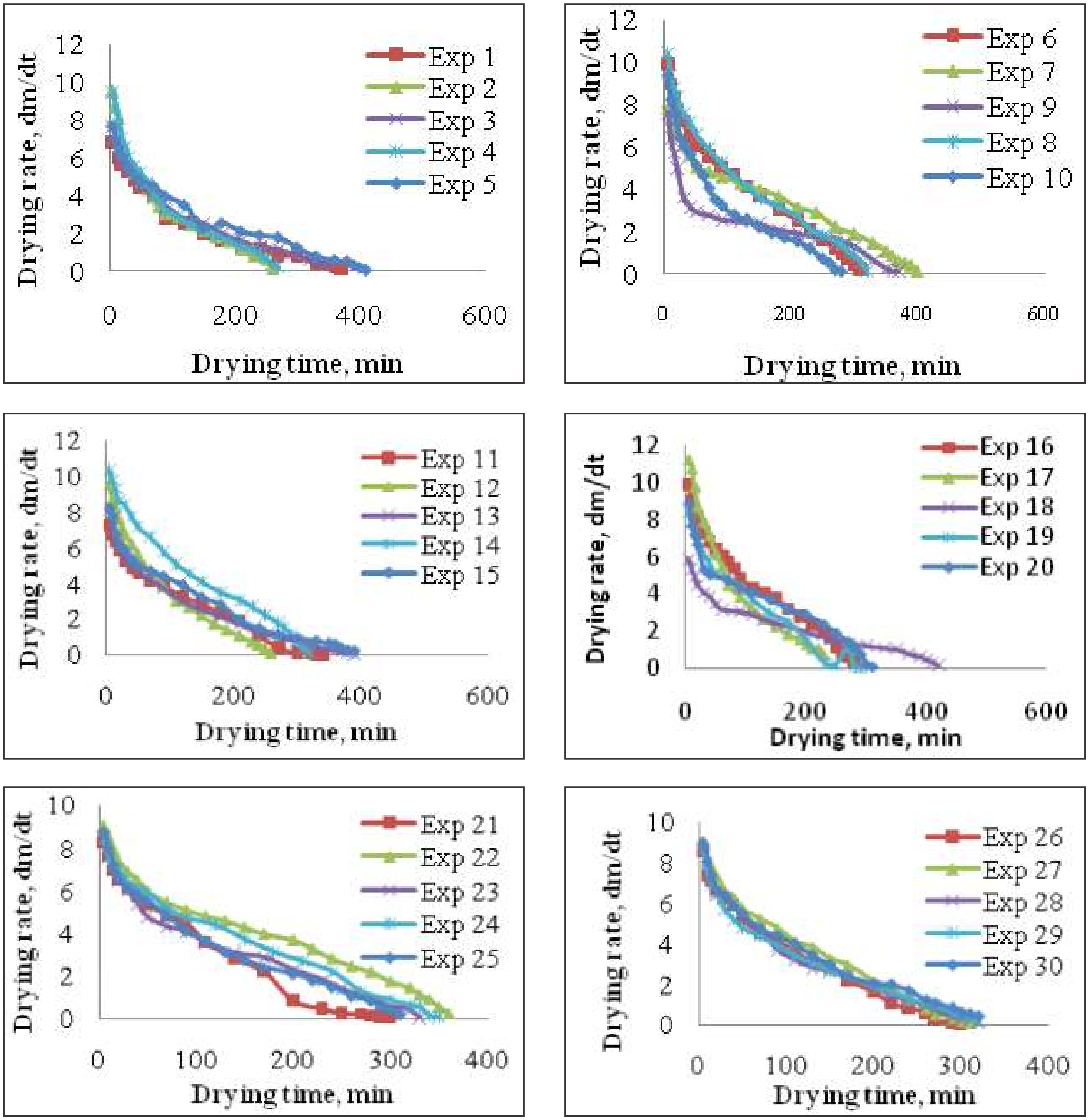


**Fig. 2:** Variation of drying rate with drying time

chlorophyll-b, dehydration ratio. The responses namely, (L*, a* and b*) for which the model was insignificant were not considered for optimization. The goal seeking begins at random starting point and proceeds up and down the steepest slope on the response surface for a maximum or minimum value of the response. The most suitable optimum point shown in the Table 2.

*Effect of variables on ascorbic acid content*

The percent ascorbic acid in the dried fenugreek ranged from 22.00 to 38.08 mg/100g. The maximum value for ascorbic acid content was obtained for the processing conditions of temperature, chimney height, product size and pre-treatment as 50°C, 0.8 m, 4 cm and

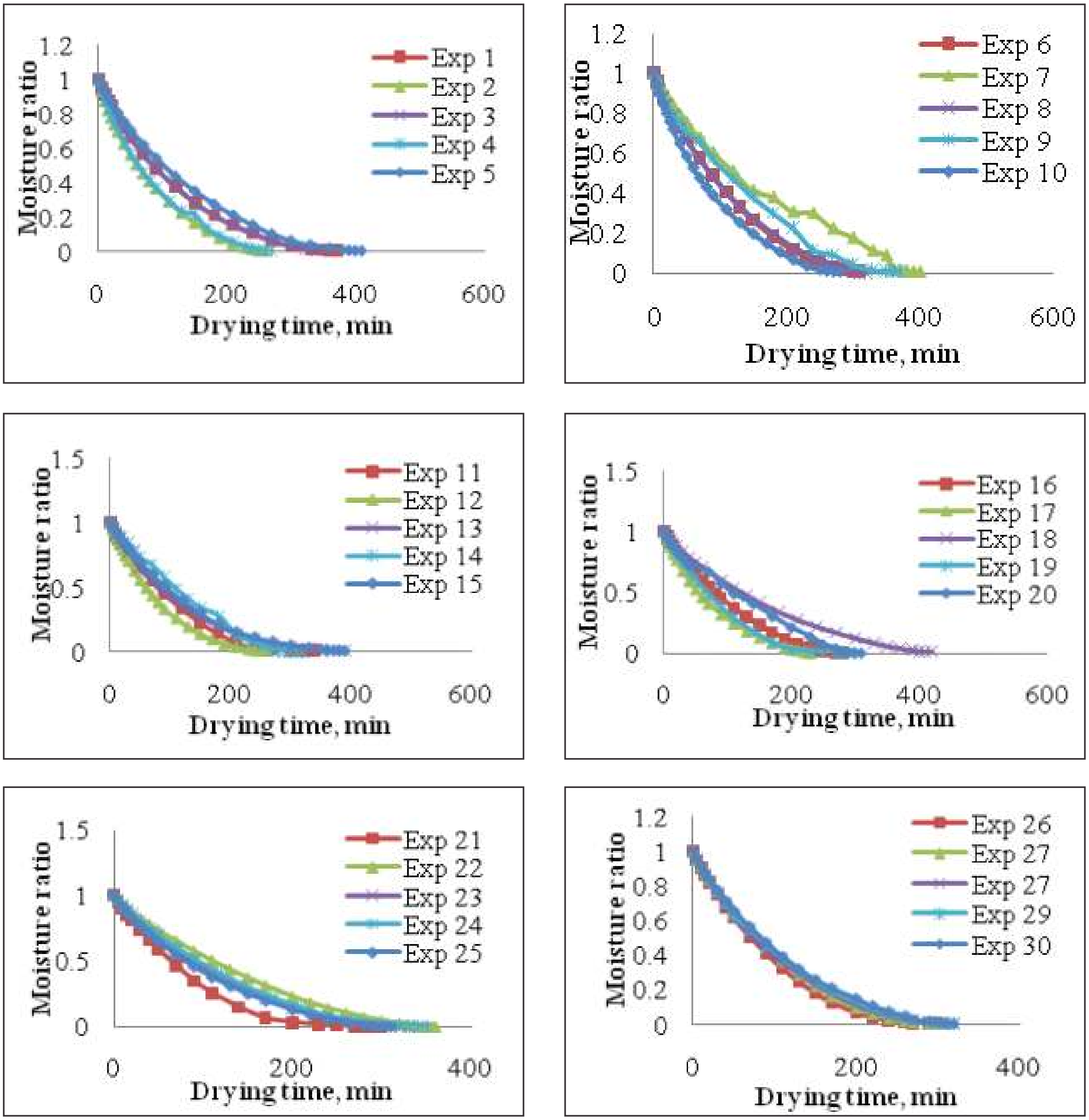


**Fig. 3:** Variation of moisture ratio with drying time

**Table 2: Optimized values of variables**

| Independent variables | Coded levels | Actual levels |
|---|---|---|
| Temperature, °C | -0.65 | 51.75 |
| Chimney height, m | -0.62 | 0.838 |
| Product size, cm | -1.0 | -1.0 |
| Pre-treatment, % | -0.27 | 4.33% |

2.5%, respectively, while the corresponding process conditions for a minimum score were 65°C, 0.9 m, 6 cm and 5%. The coefficient of determination ($R^2$) for model was 98.64% which implies that the model could account for 98.64% variability in the data. Lack of fit was not significant. The model was significant (P<0.01). Therefore second order model was adequate in describing effect of variables on ascorbic acid. The ascorbic acid content predicted by the equation:

$$\text{Ascorbic acid } (Y_1) = 31.97 - 4.60X_1 - 0.73X_2 - 0.06X_3 - 0.18X_4 + 0.12X_1X_2 - 0.11X_1X_3 - 0.33X_1X_4 - 0.09X_2X_3 - 0.09X_2X_4 + 0.14X_3X_4 - 0.13X_1^2 + 0.12X_2^2 + 0.10X_3^2 + 0.15X_4^2 \quad (12)$$

Where, $Y_1$, $X_1$, $X_2$, $X_3$ and $X_4$ are coded variable related to ascorbic acid, temperature, chimney height, product size and pre-treatment, respectively. Negative coefficient of the temperature and chimney height at linear level indicates an increase in ascorbic acid with increase in level of its variables and vice versa. Total effect of variables on ascorbic acid at linear, quadratic and interactive levels is reported in Table 3. It shows that the effect at linear and quadratic level was highly significant at (P<0.01). For interactive level effect was significant at 5% level of significance.

*Effect of variables on carotene content*

The percent carotene in the dried fenugreek ranged from 38.51 to 55.89 mg/100g. The maximum value for carotene content was obtained for the processing conditions of temperature, chimney height, product size and pre-treatment as 50°C, 0.8 m, 4 cm and 7.5%, respectively, while the corresponding process conditions for a minimum values of carotene score were 65°C, 0.9 m, 6 cm and 5%. The coefficient of determination ($R^2$) for model was 96.78% which implies that the model could account for 96.78% variability in the data. Lack of fit was not significant. The model was significant at (P<0.01). Therefore second order model was adequate to describe variables on carotene. The carotene content predicted by equation:

$$\text{Carotene}(Y_2) = 49.37 - 4.83X_1 - 0.78X_2 - 0.09X_3 - 0.07X_4 - 0.08X_1X_2 - 0.30X_1X_3 - 0.05X_1X_4 + 0.24X_2X_3 - 0.34X_2X_4 - 0.18X_3X_4 - 0.70X_1^2 + 0.23X_2^2 + 0.02X_3^2 + 0.11X_4^2 \quad (13)$$

Where, $Y_2$, $X_1$, $X_2$, $X_3$ and $X_4$ are coded variable related to carotene, temperature, chimney height, product size and pre-treatment, respectively. Negative coefficient of temperature at quadratic level shows minimum carotene at centre value and decreases with increase or decrease in parameter value from centre point. Total effect of variables at linear, quadratic and interactive levels given in Table 4. It shows that increasing the effect at linear followed quadratic level at 1% level of significance and higher $F_{cal}$ value than $F_{tab}$ value.

*Effect of variable on chlorophyll-a*

The chlorophyll-a in the dried fenugreek was ranged from 205.32 to 293.24 mg/100g. The maximum value for chlorophyll-a content was obtained for the processing

**Table 3: ANOVA for ascorbic acid content**

| SOURCE | DF | SS | MS | F-Value | F-tab |
|---|---|---|---|---|---|
| Model | 14 | 527.13 | 4.74 | 77.46* | 3.52 |
| Linear | 4 | 522.51 | 522.51 | 1092.91* | 4.89 |
| Quadratic | 4 | 2.78 | 2.78 | 5.72* | 4.89 |
| Interactive | 6 | 1.74 | 1.74 | 3.58** | 2.79 |
| Residual error | 15 | 7.29 | 0.49 | | |
| Total | 29 | 534.42 | | | |

*, ** Significant at 1, 5% level of significance respectively

**Table 4: ANOVA for carotene**

| SOURCE | DF | SS | MS | F-Value | F-tab |
|---|---|---|---|---|---|
| Model | 14 | 595.64 | 42.55 | 32.21* | 3.52 |
| Linear | 4 | 573.88 | 573.88 | 434.18* | 4.89 |
| Quadratic | 4 | 14.84 | 14.84 | 11.23* | 4.89 |
| Interactive | 6 | 4.78 | 4.78 | 3.67 | - |
| Residual error | 15 | 19.81 | 1.32 | | |
| Total | 29 | 615.45 | | | |

*, ** Significant at 1, 5% level of significance respectively

conditions of temperature, chimney height, product size and pre-treatment as 45°C, 0.9 m, 6 cm and 5%, respectively, while the corresponding process conditions for a minimum value of chlorophyll-a were 65°C, 0.9 m, 6 cm and 5%. The coefficient of determination ($R^2$) for model was 95% which implies that the model could account for 95% variability in the data. Lack of fit was not significant. The model was significant at ($P<0.01$). Therefore second order model was adequate in describing effect of variables on chlorophyll-a. The chlorophyll-a content could be predicted by equation:

$$Y_3 = 269.97 - 18.42X_1 - 2.09X_2 - 0.26X_3 - 0.17X_4 - 1.12X_1X_2 + 0.09X_1X_3 - 0.19X_1X_4 - 0.32X_2X_3 + 0.35X_2X_4 + 0.50X_3X_4 - 3.93X_1^2 + 1.53X_2^2 + 0.79X_3^2 + 1.07X_4^2 \quad (14)$$

Where, $Y_3$, $X_1$, $X_2$, $X_3$ and $X_4$ are coded variable related to chlorophyll-a, temperature, chimney height, product size and pre-treatment, respectively. Total effect of variables at linear, quadratic and interactive levels is given in Table 5. It shows that the effect of variable on chlorophyll-a at linear level was significantly higher followed by quadratic level due to higher value of SS and MS.

*Effect of variable on chlorophyll-b*

The percent chlorophyll-b in the dried fenugreek ranged from 80.77 to 105.59 mg/100g. The maximum value for chlorophyll-b content was obtained for the processing conditions of temperature, chimney height, product size and pre-treatment as 45°C, 0.9 m, 6 cm and 5%, respectively, while the corresponding process conditions for a minimum value of chlorophyll-b were 65°C, 0.9 m, 6 cm and 5%. The coefficient of determination ($R^2$) for model was 94.21% which implies that the model could account for 94.21% variability in the data. Lack of fit was not significant. The model was significant at model was significant at ($P<0.01$). Therefore second order model was adequate in describing effect of variables on ascorbic acid. The chlorophyll-b content predicted by the equation:

$$Y_4 = 98.39 - 6.17X_1 - 0.32X_2 - 0.21X_3 + 0.20X_4 - 0.16X_1X_2 - 0.25X_1X_3 - 0.65X_1X_4 + 0.40X_2X_3 + 0.42X_2X_4 - 0.26X_3X_4 - 1.73X_1^2 - 0.49X_2^2 - 0.51X_3^2 - 0.09X_4^2 \quad (15)$$

Where, $Y_4$, $X_1$, $X_2$, $X_3$ and $X_4$ are coded variable related to chlorophyll-b, temperature, chimney height, product size and pre-treatment. Eqn 15 shows highest effect of temperature on the response as compare to other variables.

*Effect of variable on dehydration ratio*

The dehydration ratio shows the bulk reduction in the weight of sample. The maximum and minimum values for dehydration ratio were 8.06 and 15.56, respectively. The corresponding conditions of temperature, chimney height, product size and pre-treatment for maximum dehydration ratio were 50°C, 1.0 m, 8 cm and 2.5%, and for minimum 55°C, 0.9 m, 2 cm and 5.0%, respectively. The coefficient of determination ($R^2$) for model was 95.44% which implies that the model could account for 95.44% variability in the data. Lack of fit was not significant. The model was significant at model 1% level of significance ($P<0.01$). Therefore second order model was adequate in describing effect of variables on dehydration ratio. The dehydration ratio content predicted by the equation:

$$Y_5 = 49.37 - 4.83X_1 - 0.78X_2 - 0.09X_3 - 0.07X_4 - 0.08X_1X_2 - 0.30X_1X_3 - 0.05X_1X_4 + 0.24X_2X_3 - 0.34X_2X_4 - 0.18X_3X_4 - 0.69X_1^2 + 0.23X_2^2 + 0.02X_3^2 + 0.11X_4^2 \quad (16)$$

Where, $Y_5$, $X_1$, $X_2$, $X_3$ and $X_4$ are coded variable related to dehydration ratio, temperature, chimney height, product size and pre-treatment, respectively. Negative coefficient of the interactive term of temperature and chimney height shows that as the value of temperature and chimney height increases above the centre value dehydration ratio decreased. If both the values of variable decreased below the central value, dehydration ratio again decreased. For increase in temperature above the central value and decrease in

**Table 5: ANOVA for chlorophyll-a**

| SOURCE | DF | SS | MS | F-Value | F-tab |
|---|---|---|---|---|---|
| Model | 14 | 8924.06 | 637.43 | 20.35* | 3.52 |
| Linear | 4 | 8269.94 | 8269.94 | 264.05* | 4.89 |
| Quadratic | 4 | 536.87 | 536.87 | 17.14* | 4.89 |
| Interactive | 6 | 28.7 | 28.7 | 0.91 | |
| Residual error | 15 | 469.78 | 31.32 | | |
| Total | 29 | 9393.83 | | | |

chimney height below the centre value or vice-versa, the dehydration ratio increased.

*Effect of variable on colour*

The maximum and minimum values for L* (51.65 and 36.73), a* (-0.77 and -4.46) and b* (42.35 and 26.14) respectively. The coefficients of determination ($R^2$) of the regression model for L*, a* and b* are 97.82%, 49.71% and 63.37%, respectively. However the model is significant for L* and insignificant for a* and b*.Although the lack of fit was not significant, the models were considered inadequate for describing the L*, a* and b* due to lower value of $R^2$ and insignificant model (P>0.05).

## CONCLUSION

It is concluded that the results of drying of fenugreek in solar tunnel drier was found best at optimized process parameters and the properties of the dried product was not lost. The maximum moisture loss percent was observed with processing conditions of temperature (55$^{o}$C), chimney height (1.1 m), product size (6 cm) and pre-treatment (5%). The ascorbic acid was highly affected by temperature as compared to chimney height and pre-treatment.

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