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EFFECT OF DRYING ON PHYSICO-CHEMICAL AND NUTRITIONAL PROPERTIES OF FENUGREEK LEAVES

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Abstract: Drying of fenugreek green leaves (*Trigonella foenum-graecum*) was conducted by using desiccant dehumidifier dryer at different temperatures viz. 45, 50 and 55°C. Obtained experimental data including moisture content, rehydration ratio, ascorbic acid and carotenoids were analysed via random factorial scheme. Comparison of data average was carried out with the help of the statistical analysis tool. Statistical analysis of experimental data showed that time, temperature, and their combined effect had a reasonable effect on the drying rate, moisture content, rehydration, ascorbic acid and carotenoids value of dried samples. However, a combined effect of time and temperature on the drying rate was not significant ($P>0.05$). The lack of fit for rehydration ratio and ascorbic acid was not significant but the values for drying rate, moisture content and carotenoids were significant. The drying rate was 6.37, 7.37 and 7.95 kg water/kg dry matter at drying air temperatures of 45, 50 and 55°C, respectively during first hour of drying (initial moisture content 88.60% wb) and declined afterwards. The results also showed that increasing time and temperature (45, 50 and 55 °C) leads to decrease in ascorbic acid (192.4, 185.3 and 170.6 mg/100g) and carotenoids (25.2, 20.5 and 17.3 mg/100g) of the samples, but it increased the value of rehydration ratio (3.8, 4.0 and 4.5 g/g) of the samples.

Key words: *drying, fenugreek green leaves, moisture content, rehydration, carotenoids*

INTRODUCTION

Inadequate attention to the post-harvest sector has been resulting in high order of losses (8 to 10 % in grains and 25 to 30% in fruits and vegetables) to the farm produces from the stage of harvesting till their use. The amount of moisture present in the food product is the most important factor in determining the extent of losses in post-harvest phase. It is a proven fact that harvesting of crops at higher moisture content and subsequent drying to safe moisture level leads towards saving of grains to the tune of 6 to 7 percent. Drying and dehydration have been also used as tool for value addition and product development from fruits and vegetables. The main aim of drying products is to

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allow longer periods of storage, minimize packaging requirements and reduce shipping weights. Dried foods are tasty, lightweight, easy to prepare and easy to store and use [1].

Green leafy vegetables are a group of edible leaves that are rich in nutrients such as vitamins and minerals. Some of the vegetables, which fall in this group, are spinach, fenugreek leaves, mustard leaves, mint, and coriander. *Trigonella foenum-graecum* is one of the popular kitchen herbs due to its unique aroma and benefits to human health. Primary processing and packaging of fenugreek has been attempted [2]. Experimental and clinical studies have demonstrated beneficial effects of fenugreek in the control of blood glucose, lipids, and platelet aggregation [3]. The defatted part of the plant is said to be responsible for the anti-diabetic action [4]. Its leaves are used in making poultice for external and internal swellings. Dry leaves are used for flavoring and seasoning also. Leaves are rich in protein, iron and vitamin A. It provides natural food fibre and other nutrients required in human body.

Producing dried products such as green leafy vegetables, fruits and many others are still common with traditional methods. Problems concerned with these methods are the long drying time, chance of microbial contamination of foods due to moisture, the undesirable quality of final products, and etc. By applying desiccant dehumidifier drying method, not only is food quality preserved, but also production time decreases considerably. Throughout history, the sun, the wind, and fire were used to remove water from fruits, meats, grains, and herbs. These are classical drying procedures. Air drying is the most frequently used dehydration operation in the food and chemical industry. The wide variety of dehydrated foods, which today are available to consumers and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process [5]. Drying process in principle is to vaporize the water in the dried material. This process is influenced by temperature, humidity and air velocity of the dryer. In the process of drying air required to heat and dry so that drying time can be shortened, but the air temperature must be adjusted to the properties of dried material.

Hot air dryers such as the desiccant dehumidifier dryer are extensively used for drying biological products at commercial level. The drying time and operational temperature of these dryers have a major effect on the quality of dried product. Desiccant dehumidifier uses desiccant wheel to lower the humidity of air in the drying system. Desiccant wheel has a good ability to absorb water in air [6]. In the process of air through desiccant wheel that is latent and sensible state, where in addition to the air becomes dry; the air will also experience an increase in temperature and decrease in relative humidity [7,8]. Reducing the relative humidity of hot air is one such approach, which increases its moisture-absorbing capacity. This helps in maintaining higher driving force for mass transfer between inner layers and the material surface.

Rehydration process is essential for dried products optimization with respect to increasing their amount and expected quality by consumers [9]. During rehydration, two opposite mass transfer flows are contributed including the water transfer into nutrition and extraction of water-soluble substances in opposite directions. Pretreatment, drying and rehydration conditions result in structural changes in food tissues, affecting quality.

With respect to the importance of the food drying process and obtaining a product with the desired quality and appropriate marketing, optimization of the operational conditions seems to be essential in order to produce dried fenugreek leaves with maximum rehydration capability, which has not been studied so far. Therefore, in this research, in addition to the investigation of fenugreek leaves drying kinetics in terms of temperature and time changes, the effects of these two parameters and their combination on moisture content, rehydration, carotenoids and ascorbic acid of dried fenugreek leaves are studied. Furthermore, Mathematical modelling of this process is investigated using the surface-response method which includes the simultaneous influence of changes

in drying temperature and time on moisture content, rehydration, carotenoids and ascorbic acid of dried fenugreek leaves.

MATERIAL AND METHODS

Fresh fenugreek (*Trigonella foenum-graecum*) leaves (average thickness 0.7 mm) was taken from the fields of Hisar, India. The roots as well as extraneous foreign material were removed and the leaves were washed in water to remove dirt and soil. Fenugreek leaves (2 kg) were used for each experiment and a single layer of the material was spread on five trays in the dryer (Fig. 1). The drying chamber containing five perforated trays was used for drying the samples. In this device, the air velocity was constant and equal to 1.5 m/s. The operational temperature and relative humidity was measured by built-in thermo-hygrometer (accuracy $\pm 2\%$) throughout the drying process with temperature range of 20 to 200°C and humidity range from 0-100%.



Figure 1. Desiccant based food dryer

Nine experiments were performed at three temperatures viz. 45, 50 and 55°C. These particular temperatures were selected in order to avoid loss of fresh colour, vitamins and texture during drying. The experiments were performed in triplicates at each temperature and experimental results were recorded. The obtained experimental results include the samples' moisture contents on wet and dry basis, rehydration and later on the dried samples were analysed for carotenoids and ascorbic acid. In order to investigate drying kinetics and moisture content, a dimensionless moisture ratio (MR) parameter was used using the following equation:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (1)$$

To calculate the rehydration parameter, the dried sample was placed in a hot water bath at 100°C for 10 minutes. Then, the amount of rehydration was calculated by the equation presented below:

$$R = \frac{A}{B} \quad (2)$$

Ascorbic acid is also known as vitamin-C and it was determined by 2, 6-dichlorophenol-indophenol visual titration method [10] and the procedure for estimation of ascorbic acid is expressed by equation (3);

$$\text{Ascorbic acid (mg per 100 g)} = \frac{A * B * V * 100}{W * \text{aliquot of the extract taken}} \quad (3)$$

Total carotenoids were calculated by column chromatography after that the readings of optical density were taken by spectrophotometer [11].

$$\text{Total carotenoids (mg/100g)} = \frac{OD \text{ at } 450 \text{ nm} * \text{volume made up}}{250 * \text{weight of sample}} * 100 \quad (4)$$

The obtained experimental data including moisture content, rehydration, carotenoids and ascorbic acid were analyzed via random factorial scheme. The time and temperature combined effects on the moisture content, rehydration, carotenoids and ascorbic acid of the samples were modelled using the surface-response fitting method. The "Design Expert" software (version 9.0) was used for surface-response fitting.

RESULTS AND DISCUSSION

Drying kinematics and moisture content. A few studies [12,13] on dehydration of herbs and spices have been reported. Analysis of the experimental data shows that drying of fenugreek leaves occurs only in the falling rate zone. Drying rate can be defined as moisture content on dry basis in unit of time. Drying rate decreases with time in three experimental temperatures, which is a result of the decrement in moisture content as time passes (Fig. 2). An increase in operational temperature in a certain time, leads to decrement in the moisture content of the samples since the evaporation rate increases with increase in temperature (Fig. 3).

The results of variance analysis of drying rate are listed in Tab. 1. In this table, degree of freedom (DF) and sum of squares for each factor are estimated according to the number of considered levels and the obtained experimental data. The Model F-value of 1513.10 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B and AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 137.74 implies the Lack of Fit is significant. Probability values have been determined from special tables with respect to the values of some of the above mentioned parameters. So the results of this column in Tab. 1 shows that drying time have a reasonable impact on the drying rate of the samples and their combined effect of time and temperature is not significant.

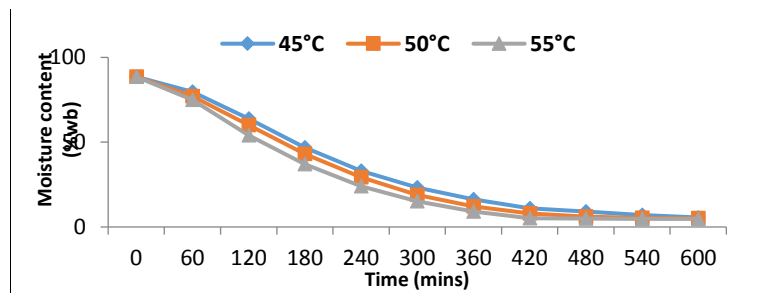


Figure 2. Influence of air temperature on the drying rate of samples in different times

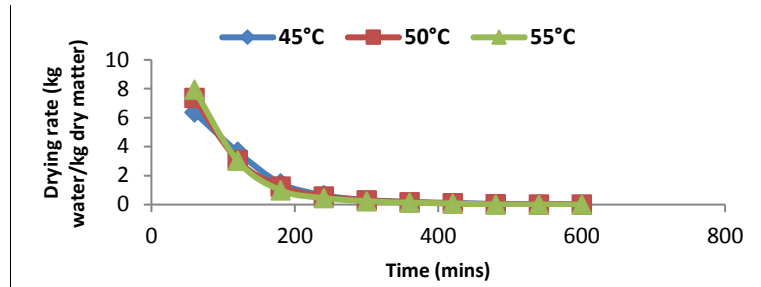


Figure 3. Effect of drying time and temperature on moisture content of the samples

Table1. Effect of different parameters on drying rate with respect to variance analysis

Source	Sum of Squares	DF	Mean Square	F Value	Prob. > F
Model	40.58	9	4.51	1513.10	< 0.0001 significant
A-Drying Temp.	1.537E-003	1	1.537E-003	0.52	0.4959
B-Drying time	28.02	1	28.02	9401.07	< 0.0001
AB	0.021	1	0.021	7.01	0.0330
Residual	0.021	7	2.980E-003		
Lack of Fit	0.021	3	6.887E-003	137.74	0.0002 significant

The results of variance analysis of moisture content are listed in Tab. 2. In this table, degree of freedom and sum of squares for each factor are estimated according to the number of considered levels and the obtained experimental data. The Model F-value of 3258.31 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B and AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 30750.00 implies the Lack of Fit is significant. So the results of this column in Tab. 2 show that temperature, time, and their combined effect have a reasonable impact on the moisture content of the samples. In this study, the surface-response fitting method was used in order to study the combined effect of time and temperature on the dried sample characteristics. Fig. 4, which shows the surface response of moisture content on wet basis, implies that the moisture content of the samples decreases with increasing time and temperature, although the time variations of the moisture content is less in the final stages of the drying process.

Table 2. Effect of different parameters on moisture content with respect to variance analysis

Source	Sum of Squares	DF	Mean Square	F Value	Prob. > F
Model	7729.50	9	858.83	3258.31	< 0.0001 significant
A-Drying Temp.	78.13	1	78.13	296.40	< 0.0001
B-Drying time	5962.32	1	5962.32	22620.29	< 0.0001
AB	17.64	1	17.64	66.92	< 0.0001
Residual	1.85	7	0.26		
Lack of Fit	1.85	3	0.62	30750.00	< 0.0001 significant

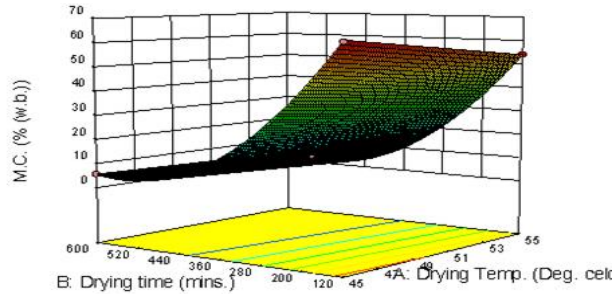


Figure 4. Surface response of moisture content (w.b.) versus time and temperature

Rehydration. Rehydration is a complex phenomenon affected by numerous factors. Important factor that would affect the rehydration is the changing of cell structure during the drying process. Different factors such as temperature, nature of the rehydration process, and type of nutrition [14] impact the rehydration amount. With respect to variance analysis of rehydration which is listed in Tab. 3, time and temperature and their combined effect have a reasonable impact on the rehydration of the samples ($P < 0.05$). The Model F-value of 55.83 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. The "Lack of Fit F-value" of 1.01 implies the Lack of Fit is not significant relative to the pure error.

With respect to Fig. 5 which shows the effect of temperature on rehydration, the value of rehydration for desiccant dryer was 3.8, 4.0 and 4.5 g/g at 45, 50 and 55 °C, respectively. Rehydration has an increasing trend with increasing time and temperature since these two parameters have an increasing effect on the samples rehydration which makes the cellular structure of the samples more porous. Fig. 6 shows the surface-response of the rehydration value. The rehydration value increases with time and temperature, however, temperature has no considerable effect at final temperatures. The required time for reaching a certain value of rehydration decreases with increase in temperature.

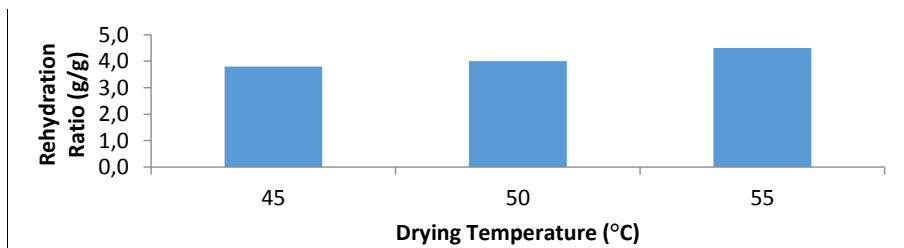


Figure 5. Temperature effect on value of rehydration

Ascorbic acid. With respect to variance analysis of ascorbic acid which is listed in Tab. 4, time and temperature and their combined effect have a reasonable impact on ascorbic acid of the samples ($P < 0.05$). The fresh fenugreek leaves contained 209.2 mg/100 g ascorbic acid.

Table 3. Effect of different parameters on rehydration with respect to variance analysis

Source	Sum of Squares	DF	Mean Square	F Value	Prob. > F
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Model	0.84	3	0.28	55.83	< 0.0001 significant
A-Drying Temp.	0.12	1	0.12	24.78	0.0003
B-Drying time	0.72	1	0.72	142.71	< 0.0001
Residual	0.066	13	5.045E-003		
Lack of Fit	0.046	9	5.065E-003	1.01	0.5384 not significant

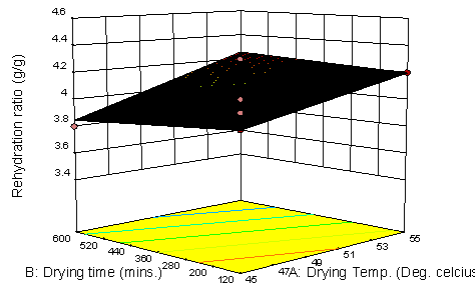


Figure 6. Surface response of rehydration value versus time and temperature

The Model F-value of 264.41 implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B are significant model terms. The "Lack of Fit F-value" of 2.23 implies the Lack of Fit is not significant relative to the pure error. Fig. 7 shows the temperature effect on ascorbic acid of the samples. It is observed from the Fig. 7 that the ascorbic acid retention among the dehydrated samples was 192.4, 185.3 and 170.6 mg/100g at drying air temperatures of 45, 50 and 55°C respectively.

Fig. 8 shows the surface-response of the ascorbic acid has a decreasing trend with increasing time and temperature since these two parameters have a decreasing effect on the ascorbic acid of the samples. The ascorbic value decreases with increase in temperature.

Table 4. Effect of different parameters on ascorbic acid with respect to variance analysis

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	1086.59	3	362.20	264.41	< 0.0001 significant
A-Drying Temp.	892.53	1	892.53	651.56	< 0.0001
B-Drying time	194.04	1	194.04	141.66	< 0.0001
Residual	17.81	13	1.37		
Lack of Fit	14.85	9	1.65	2.23	0.2286 not significant

Figure 7. Temperature effect on value of ascorbic acid

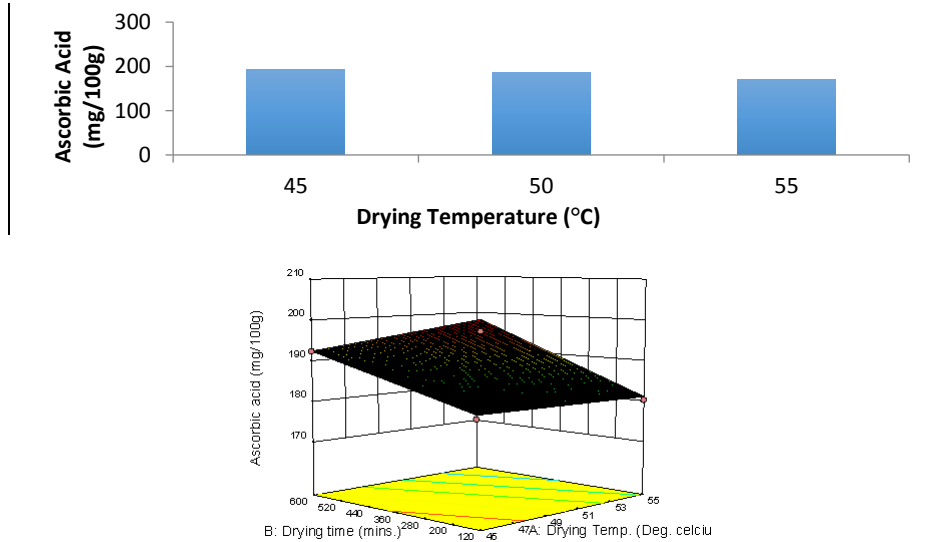


Figure 8. Surface response of ascorbic acid versus time and temperature

Carotenoids. With respect to variance analysis of carotenoids which is listed in Tab. 5, time and temperature and their combined effect have a reasonable impact on the carotenoids of the samples ($P < 0.05$). The fresh fenugreek leaves contained 32.4 mg/100g of total carotenoids. Fig. 9 shows the temperature effect on the carotenoids of samples. It was observed that the carotenoids retention among the dehydrated samples was 25.2, 20.5 and 17.3 mg/100g at drying air temperatures of 45, 50 and 55°C, respectively. Fig. 10 shows the surface-response of the carotenoids have a decreasing trend with increasing time and temperature since these two parameters have a decreasing effect on the carotenoids content of the samples. Fig. 10 shows the surface-response of the carotenoids value. The carotenoids value decreases with increase in temperature.

Table 5. Effect of different parameters on carotenoids with respect to variance analysis

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	155.66	3	51.89	115.24	< 0.0001 significant
A-Drying Temp.	132.84	1	132.84	295.06	< 0.0001
B-Drying time	22.78	1	22.78	50.60	< 0.0001
Residual	5.85	13	0.45		
Lack of Fit	5.65	9	0.63	12.56	0.0133 significant

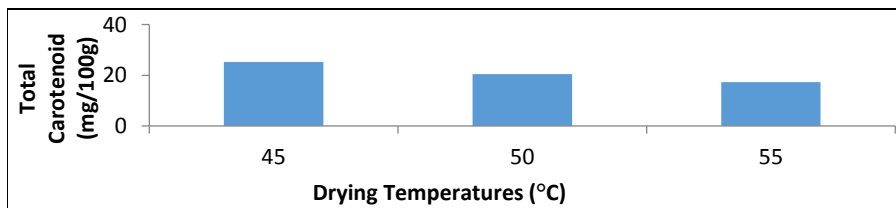


Figure 9. Temperature effect on value of carotenoids

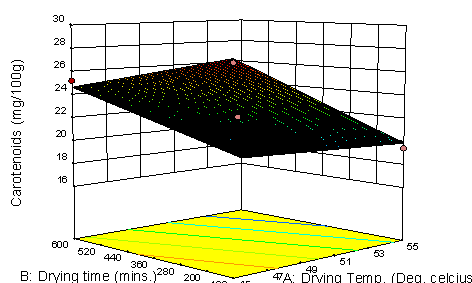


Figure 10. Surface response of carotenoids versus time and temperature

CONCLUSIONS

A low-temperature desiccant based food drying system with temperature and airflow control was presented, evaluated and analysed. Statistical analysis of the experimental data showed that time, temperature, and their combined effect have a reasonable impact on the moisture content, ascorbic acid, carotenoids and rehydration of dried fenugreek leaves ($P < 0.05$). However, the combined effect of time and temperature on the value of drying rate was not significant. Drying was conducted at three drying air temperatures of 45, 50 and 55°C. At 45°C the drying time was higher and took 600 minutes to complete the drying. It took 540 and 420 minutes at drying air temperature of 50 and 55°C to dry fenugreek leaves to equilibrium moisture content of 5 % from initial moisture content of 88.60 %. With increase in drying rate and temperature, contractile stresses occur in the cell wall structure which increases the porosity thereby increasing the rehydration ratio. The product dried in desiccant dryer at low temperature (45°C) had superior green colour and maximum retention of ascorbic acid and total carotenoids. From this study it was concluded that desiccant dryer reduced the drying time and gave better quality of dried fenugreek leaves and hence is a promising alternative for food drying. This dryer can be used for drying vegetables like cabbage, eggplant, carrot, and green leafy vegetables.

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UTICAJ SUŠENJA NA FIZIČKO-HEMIJSKA I NUTRITIVNA SVOJSTVA LISTOVA PISKAVICE

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Sažetak: Zeleni listovi piskavice (*Trigonella foenum-graecum*) sušeni su na temperaturama od 45, 50 i 55°C. Dobijeni eksperimentalni podaci, uključujući sadržaj vlage, odnos dehidracija, askorbinske kiseline i karotenoidi su statistički obrađeni. Analiza je pokazala da su vreme, temperatura i njihov kombinovani efekat imali značajan uticaj na brzinu sušenja, sadržaj vlage, dehidraciju, askorbinsku kiselinu i karotenoide suvih uzoraka. Kombinovani efekat vremena i temperature na stope sušenja nije bio značajan ($P > 0,05$).

Ključne reči: sušenje, zeleni listovi piskavice, sadržaj vlage, rehidracija, karotenoidi

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