Research Article

# Development of Multi Product Solar Dryer and its Evaluation for Fenugreek Leaves

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**Abstract**

Due to the low income of the rural population in developing countries, the relatively high initial investment for solar dryers still remains a barrier to a wide application. The opportunity to produce high quality marketable products appears to be a chance to improve the economic situation of the farmers. A simple low cost multi product solar dryer was developed and evaluated for drying of fenugreek leaves in semi continuous mode. Average solar radiation intensity varied from 515-666 W/m$^2$, maximum ambient temp ($^o$C) varied from 31-33$^o$C and thermal efficiency (%) varied from 21.4-35.4% for different days of the experimental study. Lesser ΔE for solar dried samples (5.65) shows less deviation from fresh colour as compared to sun dried samples (6.55). Higher total chlorophyll was reported for solar dried samples (289.20 mg/100g, dw basis) as compared to sun dried samples (164.60 mg/100g, dw basis). Considering the cost of fresh and dried fenugreek the profit per day of Rs. 194/- was calculated for drying of fenugreek. Payback period was found to be 181 drying days for drying of fenugreek.

**Keywords:** Solar drying, Multi product dryer, development, fenugreek, quality, economics

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## Introduction

The relevance of solar energy in drying practice of agriculture product has tremendous potential as it can easily provide the low temperature heating essential for drying. The agricultural products have maximum permissible drying temperature range of 55-70$^o$C. The drying practice using solar energy ranges from traditional open sun drying to solar dryers. Open sun drying has many problems such as contamination by dust, insect, infestation, microbial attack, slow drying rate, more drying time and quality of dried products is poor [1]. In comparison to open sun drying, solar dryers generate higher temperature, lower relative humidity, lower product moisture content, reduced spoilage during the drying process [2, 3]. According to a survey conducted in several countries in Asia Pacific region the best potential and popular solar dryers are i) Natural convection cabinet dryer ii) Forced convection indirect type and iii) Green house type dryer [4]. The high temperature dryers used in commercial countries are found to be economically viable in developing countries only on large agro sectors and generally it is not affordable by small and medium entrepreneurs because of high cost and process variability [5-7].

Fenugreek *(Trigonella foenum-graecum* L.*)* most popularly known as "Methi", is an Indian herb; the stems, leaves and twigs are used for cooking, in medications and for their nutritional value. It is a green leafy vegetable that is highly perishable in nature, due to high respiration rate; consequently, sensory as well as nutrient loss occurs at a very high rate. Fresh fenugreek leaves can be stored for 9 days without any adverse effect on bioactive compounds in polypropylene (PP) film package (34µm), non-perforated at 15°C and 75 per cent [8]. Preservation of these greens can prevent huge wastage as well as make them available in the lean season at remunerative prices. Dehydration is the process of removal of moisture due to simultaneous heat and mass transfer. It is one of the methods of preservation of foods, which 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 the present study, a simple low cost multi product solar dryer was developed and used for solar drying of fenugreek leaves. This dryer is easy to operate, requires no training and it is low cost since it is made by locally available materials. The developed multi-product solar dryer was tested for drying of fenugreek leaves in semi continuous mode in comparison to open sun drying. The quality of product in terms of moisture content, colour, chlorophyll content and rehydration characteristics was determined in comparison with open sun dried samples.

## Materials and Methods

### *Description of developed dryer*

A new modular design of solar dryer that absorbs solar radiation on inclined surface has been developed. A schematic and photograph of one module of the solar dryer is shown in **Figure 1**. It has separate solar air heater and drying chamber. These are described below:

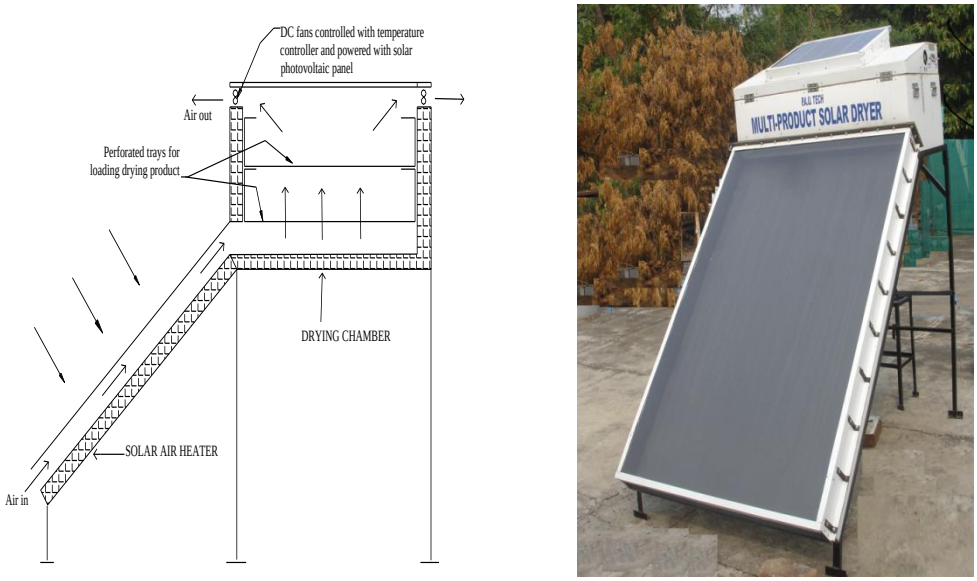


**Figure 1** Multi Product Solar Dryer

### *Solar air heater*

The solar air heater works by natural circulation of air. The aperture area of solar air heater is 2.25 $m^2$ (1.87 m x 1.20 m). The duct spacing has been kept as 10 cm for natural air flow through the dryer. At the bottom and sides, a thermocole insulation of 5 cm is provided. A GI sheet painted dull black is fixed above thermocole using 1 cm thick spacers. The GI sheet is painted dull black and it acts as absorber of solar radiation. The spacers are used between GI sheet absorber and thermocole so as to avoid direct contact between the hot absorber and thermocole. The glazing is 4 mm thick transparent glass sheet. The opposite ends of this duct are open for ambient air inlet and hot air outlet to drying chamber.

### *Drying chamber*

At the top of solar air heater is a drying chamber for holding the product to be dried. It has been made to achieve semi-continuous drying. For achieving semi-continuous drying, two trays one above the other have been provided and air flows through them. At the start, the fresh product is loaded in the lower tray up-to the top. During subsequent drying days, the partially dried product from upper tray is mixed with product in lower tray and fresh product is again loaded in the upper tray. This causes better utilization of heat in drying air before exhausting to atmosphere. The lower tray has 108.0 cm x 48.5 cm cross-section and 19.5 cm height. The upper tray cross-section is 106.5 cm x 47.0 cm and 6.5 cm height. Both the trays are made of GI sheet with wire mesh at the bottom. The overall dimensions of the drying chamber are 123.0 cm x 63.0 cm cross-section and 37.0 cm height. The height of plenum is 10.0 cm. The chamber is insulated from bottom and sides with 7.5 cm thick thermocole insulation. Four openings of 8 cm diameter have been provided for air outlet in the sides walls of the drying chamber near the top. Four thermostatically controlled DC electric fans of rating 3W each are fixed in the four openings provided near the top so as to maintain the air temperature at inlet to drying chamber below permissible limit. These fans are operated by 20 Wp solar photovoltaic panel using DC temperature controller.

### *Design features*

The dryer has following useful design features as compared to other designs:

- Due to inclined absorber, the solar energy input per unit aperture area is more than that in solar dryers with horizontal aperture especially at higher latitudes during winter.
- The dryer can be used in any of the three modes viz., natural circulation mode, fan-assisted mode and combination of natural and fan assisted mode. For initial drying only fan assisted mode can be used for higher thermal efficiency.
- There is no possibility of spoilage of product due to higher drying temperature, because for a given product maximum allowable temperature can be set using thermostat. Also it can be used for any product by setting the maximum permissible temperature for that product.
- When fan starts, the temperature of drying air reduces below the maximum allowable temperature and at the same time excess heat input is used.
- Drying of agricultural product is under shade, so there is no problem of discolouration, vitamin loss, etc.
- The dryer works in semi-continuous mode to achieve higher thermal efficiency during subsequent drying days.

***Evaluation of solar dryer for drying of fenugreek***

The developed multi-product solar dryer (Figure 1) was tested for drying of fenugreek leaves in the demonstration area of School of Renewable Energy Engineering, PAU, Ludhiana during October, 2016. Fresh fenugreek was procured from the local market. Roots were cut off and the remaining crop was washed to remove dirt and dust sticking to it. Leaves and some fine stems were kept and remaining was discarded. The semi-continuous loading mode was followed and 3.2 kg of fenugreek leaves was loaded in both the lower and upper tray each. During subsequent drying days due to shrinkage of product, more fresh product was added in the dryer. The semi-continuous loading mode was followed and 3.2 kg of fresh product was added each on 2$^{nd}$, 3$^{rd}$, 4$^{th}$, 5$^{th}$, 6$^{th}$, 7$^{th}$ and 8$^{th}$ drying days. Maximum ambient temperature, drying chamber inlet and outlet temperatures, drying chamber inlet and outlet relative humidities and average solar radiation intensity were recorded on hourly basis during the experiment. Weight of fenugreek leaves and thermal efficiency of the dryer was calculated on daily basis for drying of fenugreek leaves. Quality was evaluated for fenugreek leaves for product dried in solar dryer and in open sun. For fenugreek leaves, the moisture content, colour and chlorophyll content were investigated. Moisture content was determined using standard air oven method. The samples were oven dried at 100 ± 2°C in uncovered pre-weighed petri dishes [9]. After drying, petri dishes were covered with lid and cooled in desiccators containing silica gel before weighing.

$$Moisture\ Content, \%\ wb = \frac{(W_2 - W_3)}{(W_2 - W_1)}\ x\ 100$$

Where, $W_1$, $W_2$ and $W_3$ are the weights of empty petri dish, petri dish with initial wet sample and petri dish with dried sample, respectively.

The color analysis (L, a, b) of fresh, open sun dried, solar dried sample was measured by using Color reader (Make: Konica Minolta; Model: CR-10). Total color difference (ΔE) was determined using the equation.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Where, ΔL = (L dried– L fresh sample), Δa = (a dried – a fresh sample); Δb = (b dried– b fresh sample).

Total chlorophyll pigment was determined and quantified using the given procedure [10]. 1 g sample was homogenized with 10 mL of acetone and n-hexane (4:6) using a tissue homogenizer (Labco, India) for 30 s over ice. The homogenized solution was allowed to settle down. Then, 1 mL of the supernatant was taken and was diluted with 9 mL of acetone and n-hexane (4:6), more dilution can be done if required. The resulting solution was analyzed spectro-photometrically with the help of and UV-Vis spectrophotometer (Model Spectroscan 80DV, Biotech Engineering management Company Limited, UK). The optical density was measured at 663, 645, 505 and 453nm using acetone and n-hexane (4:6) as a blank. Chlorophyll concentrations (mg/100ml) were quantified using the following equations and then expressed as mg/100g fw of sample.

$$Chlorophyll\ a = 0.999A_{663} - 0.989A_{645}$$
$$Chlorophyll\ b = 0.328A_{663} - 1.77A_{645}$$
Total chlorophyll = Chlorophyll a + Chlorophyll b

Where, $A_{663}$, $A_{645}$, $A_{505}$ and $A_{453}$ are the absorbances at 663, 645, 505 and 453 nm, respectively.

The rehydration ratio (RR) was calculated after the completion of drying procedure using the following formula [9].

$$Rehydration\ ratio = \frac{W_1}{W_2}$$

where $W_1$ is the weight of sample after rehydration and $W_2$ is the weight of taken for rehydration.

The coefficient of rehydration (COR) was calculated by using the formula [9]:

$$Coefficient\ of\ rehydration = \frac{W_2 \times (100 - M_1)}{100 \times (W_1 - M_2)}\ x\ 100$$

Where, $W_2$ is the weight of sample after rehydration (g), $W_1$ is the weight of dried sample before rehydration (g), $M_1$ is the moisture content on wet basis of sample before drying and $M_2$ is the amount of moisture present in dried sample (g).

***Economic analysis***

Keeping in view the cost of fresh and dried fenugreek the profit per day was calculated for drying of fenugreek in multi product solar dryer. Payback period was further calculated using the fixed cost of the equipment if the system runs in semi continuous mode for drying of fenugreek.

## Results and Discussion

The initial moisture content of fenugreek leaves was 88.5% and average final moisture content was 4.6%. For comparison, the drying was also done by spreading the product in open sun in a tray of size 36 x 36 cm; 200 g of product got reduced to moisture content of 7.9% in 3 drying days. The loading per unit of tray area was 6.1 kg/m$^2$ and 1.54 kg/m$^2$ for solar dryer and open sun drying, respectively.

**Table 1** Weight of fenugreek leaves, maximum ambient temperature, average solar radiation intensity and thermal efficiency for drying of fenugreek leaves

| Day no. | Time | Drying Product (kg) | | Dried product removed (kg) | Average solar radiation intensity | Maximum ambient temperature ($^o$C) | Thermal efficiency (%) |
|---|---|---|---|---|---|---|---|
| | | Lower Tray | Upper Tray | | | | |
| 1 | 10:00 | **3.20** | **3.20** | - | 542 | 33.0 | 35.4 |
| | 16:00 | 1.21 | 1.46 | - | | | |
| 2 | 10:00 | 2.00 | **3.20** | | 666 | 32.0 | 23.9 |
| | 16:00 | 0.80 | 1.30 | 0.80 | | | |
| 3 | 10:00 | 1.22 | **3.20** | | 656 | 32.0 | 22.5 |
| | 16:00 | 0.40 | 1.15 | 0.40 | | | |
| 4 | 10:00 | 1.08 | **3.20** | | 620 | 32.0 | 22.1 |
| | 16:00 | 0.41 | 1.20 | 0.41 | | | |
| 5 | 10:00 | 0.80 | **3.20** | | 515 | 31.0 | 23.8 |
| | 16:00 | 0.36 | 1.25 | 0.36 | | | |
| 6 | 10:00 | 1.16 | **3.20** | | 639 | 31.5 | 22.4 |
| | 16:00 | 0.37 | 1.20 | 0.37 | | | |
| 7 | 10:00 | 1.09 | **3.20** | | 627 | 32.0 | 21.4 |
| | 16:00 | 0.38 | 1.30 | 0.38 | | | |
| 8 | | | | 0.35 | | | |

*Values in bold are the fresh product loaded

The weight of fenugreek leaves, maximum ambient temperature, average solar radiation intensity and thermal efficiency for drying of fenugreek leaves is shown in **Table 1**. Temperature and relative humidity at inlet and outlet of drying chamber, ambient temperature and solar radiation intensity during a typical drying day for fenugreek leaves is

shown in **Figure 2**. A total of 25.60 kg of fresh fenugreek leaves was loaded in solar dryer spread over 8 days and it got dried to 3.07 kg. In semi-continuous mode, on an average 400g of dried product was removed per day. Average solar radiation intensity varied from 515-666 W/m$^2$, maximum ambient temp ($^o$C) varied from 31-33$^o$C and thermal efficiency (%) varied from 21.4-35.4% for different days of the experimental study.

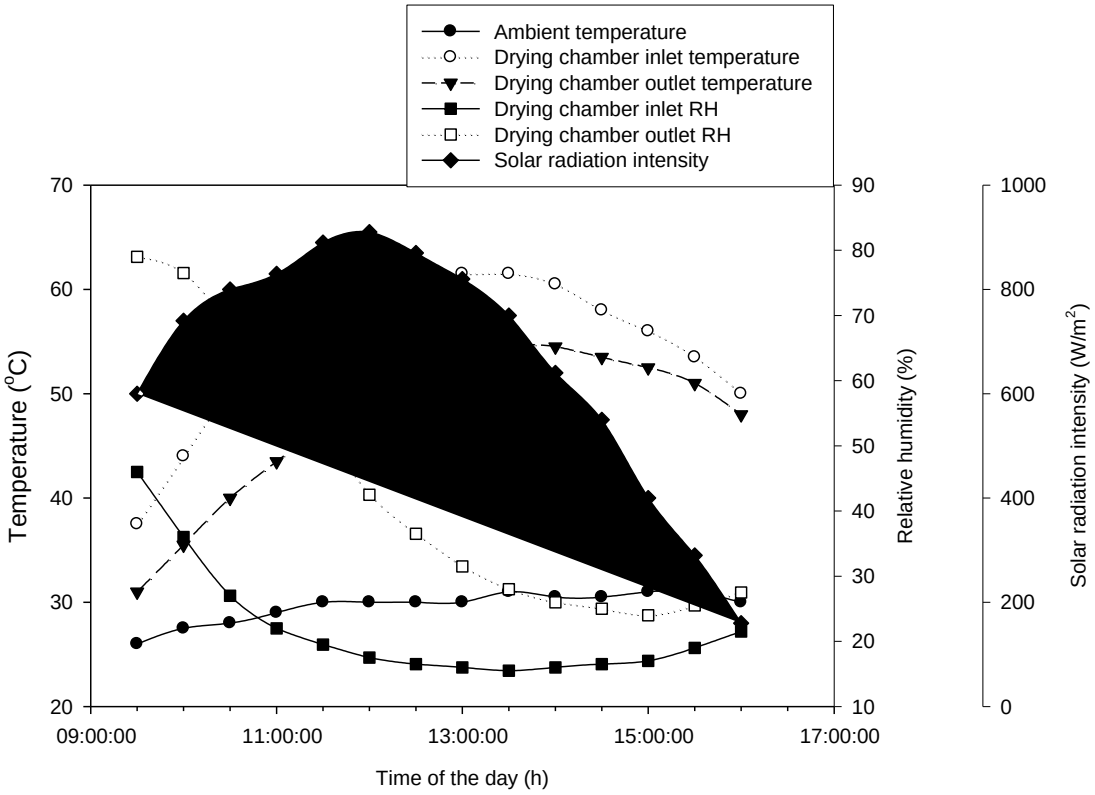


**Figure 2** Temperature and relative humidity at inlet and outlet of drying chamber, ambient temperature and solar radiation intensity during a typical drying day

The average values ± SD values for various quality attributes are given in **Table 2**. The initial moisture content of the fenugreek leaves loaded was 88.5% and the final moisture content for solar dried was 4.6% and for open sun drying was 7.74%. Negative 'a' value indicates green colour. A higher value of negative 'a' for solar dried samples (-4.1) as compared to sun dried sample (-3.3) indicates that solar dried samples were greener than sun dried samples. Total colour difference (ΔE) for solar dried and sun dried samples was 5.65 and 6.55, respectively. Lesser ΔE for solar dried samples shows less deviation from fresh colour. Total chlorophyll values for fresh, solar dried and sun dried fenugreek were found out to be 947.8, 289.2 and 164.6 mg/100g, dw basis. Solar dried samples reported higher total chlorophyll than sun dried samples.

**Table 2** Quality attributes for fenugreek leaves

| S. No. | Fenugreek | Moisture Content (%, wb) | Colour | | | | Total Chlorophyll Content (mg/100g, dw basis) |
|---|---|---|---|---|---|---|---|
| | | | L | a | b | ΔE | |
| 1 | Fresh | 88.50 ± 0.28 | 39.70 ± 0.88 | (-)8.60 ± 0.75 | 19.20 ± 0.75 | - | 947.80 ± 11.68 |
| 2 | Solar dried | 4.60 ± 0.56 | 38.60 ± 0.97 | (-)4.10 ± 0.95 | 16.27 ± 1.01 | 5.65 ± 0.16 | 289.20 ± 9.95 |
| 3 | Sun dried | 7.74 ± 0.35 | 42.50 ± 1.19 | (-)3.30 ± 0.46 | 16.87 ± 1.05 | 6.55 ± 0.65 | 164.60 ± 8.50 |

Note: Average ± SD values

Rehydration characteristics viz. rehydration ratio and coefficient of rehydration were determined for the dried product. The average ± SD values for various rehydration characters are given in **Table 3**. The rehydration ratio varied from 4.79-5.20 for solar dried and 4.73-5.21 for sun dried for 1-4 minutes rehydration times. Corresponding values for coefficient of rehydration were 0.56-0.61 for solar dried and 0.57-0.62 for sun dried, respectively. Almost comparable rehydration characteristics were observed for solar and sun dried samples. Coefficient of rehydration values became constant after 2-3 minute time in both cases (Table 3).

**Table 3** Rehydration characteristics of dried fenugreek leaves

| Rehydration characteristics | Rehydration Time (min) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | |
| | Solar | Sun | Solar | Sun | Solar | Sun | Solar | Sun |
| Drained Weight (g) | 9.58 ± 0.11 | 9.45 ± 0.09 | 10.33 ± 0.36 | 10.23 ± 0.36 | 10.38 ± 0.13 | 10.37 ± 0.24 | 10.4 ± 0.19 | 10.41 ± 0.25 |
| RR | 4.79 ± 0.05 | 4.73 ± 0.04 | 5.17 ± 0.18 | 5.12 ± 0.18 | 5.19 ± 0.07 | 5.19 ± 0.12 | 5.2 ± 0.09 | 5.21 ± 0.12 |
| COR | 0.56 ± 0.01 | 0.56 ± 0.01 | 0.61 ± 0.02 | 0.60 ± 0.02 | 0.61 ± 0.01 | 0.61 ± 0.01 | 0.61 ± 0.01 | 0.61 ± 0.01 |

Note: Average ± SD values

***Economics of solar dryer for drying of fenugreek leaves***

Initially, about 6.4 kg of produce was fed to the solar dryer in both the trays thereafter about 3-4 kg of produce was fed in the consecutive days. Fixed cost of the system is Rs. 35,000. Keeping in view the cost of fresh and dried fenugreek the profit per day of Rs. 194/- was calculated for drying of fenugreek in multi product solar dryer. Payback period was further calculated as 181 drying days using the fixed cost of the equipment if the system runs in semi continuous mode for drying of fenugreek (**Table 4**).

**Table 4** Economics of Solar Dryer for drying of fenugreek leaves

| S.No. | Description | Fenugreek leaves |
|---|---|---|
| 1. | Capacity of solar dryer (fresh product loading per day) | 3-4 kg |
| 2. | Fixed cost | Rs. 35000 |
| 3. | Life in years | 15 years |
| 4. | Interest rate on loan | 8% |
| 5. | Equated annual instalment (10 years) | Rs. 5216 |
| 6. | Recurring cost | Nil |
| 7. | Cost per kg of fresh product | Rs. 10 |
| 8. | Cost per kg of fresh product used for drying considering trimming losses of 15% for fenugreek leaves | Rs. 11.5 |
| 9. | Cost per kg of dried product (About 10 kg of fresh product gets reduced to 1 kg of dried product) | Rs. 115 |
| 10. | Cost of dried product per day (in semi-continuous mode) | Rs. 115 x 0.4 = Rs.46 |
| 11. | Cost of dried product in the market | Rs. 600/ kg |
| 12. | Market price of product dried in solar dryer per day | Rs. 600 x 0.40 =Rs. 240 |
| 13. | Profit /day | Rs. (240-46) =Rs. 194 |
| 14. | Payback period | 35000/194 ≈181 drying days |

## Conclusion

The developed multi product solar dryer was tested for fenugreek leaves. Lesser ΔE for solar dried samples (5.65) as compared to sun dried samples (6.55) was observed. Higher total chlorophyll was reported for solar dried samples (289.20 mg/100g, dw basis) as compared to sun dried samples (164.60 mg/100g, dw basis). Almost comparable rehydration characteristics were observed for solar and sun dried samples. It can be concluded that fenugreek can be effectively dried in multi product solar dryer with good quality attributes. The profit per day for running the multi product solar dryer in semi continuous mode was Rs. 194. Payback period was found out to be as 181 drying days if the system runs in semi continuous mode for fenugreek.

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