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Studies on drying characteristics and techno-economic analysis of sprouted moth beans (*Vigna aconitifolia*) in solar tunnel dryer

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ABSTRACT

A commercial solar tunnel dryer (STD) was evaluated for drying of sprouted moth beans and also its techno-economic analysis was carried out. The maximum temperature 58ºC was recorded at 13:00h in STD during the drying process i.e. 41.0% (34.2ºC) higher than the maximum ambient temperature at the same time. A total drying time of 13:50h were required in STD to reduce the initial moisture content from 177.7% dry basis (d.b) to a final moisture content of 16.6% (d.b). However, the open sun drying took 16.5 drying hours to obtain desired moisture content. The net present worth and cost-benefit ratio of dryer was Rs.5,83,910.68/- and 1.19, respectively. However, the payback period for STD was 15 month 8 days. The cost economics of dried products were proved better for STD than open sun drying method. STD samples were found to be of good quality in terms of color, taste and aroma as compared to open sun dried (OSD) with an overall drying efficiency of STD was 19.7%. Therefore, the evaluated solar tunnel dryer were recommended for the drying of sprouted moth beans.

Key words: Drying time, Moisture content, Solar tunnel dryer, Sprouted moth beans.

INTRODUCTION

Moth beans are widely grown legume in the world and their dietary and economic importance is globally appreciated and recognized. Moth beans not only add variety to human diet, but also serve as an economical source of supplementary proteins (23.6 g), calcium (202 mg) and vitamin A, E and C that makes an excellent supplement to cereal diet (Kalbande *et al*., 2016) for a large human population in developing countries (Bishnoi 1992; Sood *et al.*, 2002; Vijaykumar *et al*., 2016). India is a major moth producing country with annual production of 2.77 lakh tonnes in a total area of 9.26 lakh hectare during 2012-15. The production of moth bean was highest in Rajasthan, contributing 94.49% followed by Gujarat 3.6 (Tiwari and Shivhare, 2016). In India, moth beans are consumed in the form of sprouts which are essentially a pre-digested food with an increased nutritional quality. The benefits of sprouted moth beans are as follows, develop immunity against various diseases, full of antioxidants that contend free radicals and act as a panacea for many diseases, enhances the digestibility and thus make it the superb food, sprout increases vigor and vitality so these are rejuvenating foods (Dixit and Swami, 2016). The process of sprouting requires more time but nutrients percentage of vitamin C, iron, riboflavin, niacin and phosphorous increase after sprouting.

The current demand of high-quality foods in the food market requires dehydrated products with high nutritional and organoleptic properties with similar levels as found in the initial fresh product. The process of dehydration which acts as a preservation technique and the basic principle of dehydration is the removal of moisture through simultaneous heat and mass transfer, that provide more shelf-life, reduces weight and volume (Bakshi *et al.*, 2013; Hota *et al.*, 2017). However, sprouts are highly perishable due to high moisture content and may be stored up to 5 to 10 days at 0°C (32 °F) with 95 to 100% RH (De Ell *et al.*, 2000). Keeping all in view, there is need to remove the moisture from it to inactivate the water activities in order to preserve them. Therefore, the present study was under taken to study the drying behaviour of sprouted moth bean under solar tunnel dryer. In addition, the drying process should have a low production cost and a low environmental impact. Hence, the techno-economics analysis of solar tunnel dryer was also carried out.

Solar drying system is one of the most attractive and promising applications of solar energy systems for food preservation, however, a traditional open sun drying is labor intensive and a major disadvantage is contamination of the products by dust, birds and insects; some percentage would be lost usually or damaged. Moreover, an aroma, colour, nutrients and volatile chemical compound get lost significantly (Kalbande *et al.*, 2016; Badgujar *et al.*, 2018).

MATERIALS AND METHODS

In a present study, a commercial solar tunnel dryer (STD) of 18 m^2 area were installed at Ramakrishna Agro

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Table 1: Technical specification of STD.

Particulars	Specifications
Aperture area, m^2	24.25
Width of dryer, m	3.00
Length of dryer, m	6.00
Drying tray area, m^2	2.5 (1.6 m x 1.6 m)
Number of trays	04 on each trolley
Number of trolleys	2 Number., (1.67 x 3.12 x 1.2 m)
Height of tunnel, m	2.0
Plastic cover, UV stabilized	200 μm
Chimney	2 Nos., Ø 0.15 m, H =0.75m
Fresh air vent area, m^2	0.05
Exhaust Fan, single phase,40 Wp, 1400 rpm	1 Nos, Brushless AC
Door	1.80 m x 0.75 m

Vegetables and Food Products at *Kodoli* town of Maharashtra state by the Department of Renewable Energy Studies Dr. PDKV, Akola and its technical specifications were given in Table 1 (Fig 1). The installed dryer was used for drying of supplementary food products such as sprouted moth bean (*Vigna aconitifolia*), Indian Gooseberry (*Phyllanthus emblica*) and Sugar Beet (*Beta vulgaris s.*). Therefore, the performance of dryer was evaluated for sprouted moth beans and compared with traditional open sun drying. The moth beans were uniformly spread in the layer thickness of 3 cm on the flat rectangular container. The container were further placed on the 4 trays (Tray A, B, C and D) located at an equidistance of 40 cm from each other and drying observation were recorded. In traditional open sun drying method, 3 cm thick smaples were placed for sun drying in same rectangular container used for STD drying. Also, its techno-economic analysis was carried out by different indicators such as net present worth (NPW), benefit-cost ratio (B:C) and payback period to assess its economic feasibility.

The fresh product was chosen for the experiment of sprouted moth beans and the following process is done as shown in Fig 2 (Bala, 2016). The three digital thermometer (range -50 to 200^0C) were used to measure the temperature inside each tray and ambient temperature. The compact hygro-thermometer and analog solarimeter (range 0 to 120 $mWcm^{-2}$) were used to measure the relative humidity and solar radiation. The solarimeter were fixed at fix position throughout the experiment.

Fig 1: Schematic view of a solar tunnel dryer.

Raw Moth Beans
⇓
Cleaning & Grading
⇓
Washing
⇓
Soaking in Water (12 to 16 h)
⇓
Tight covering in cotton cloth
⇓
Sprouted Moth Beans
⇓
Preparation of sample
⇓
Drying

Fig 2: Process flow chart of sprouted moth beans.

Study of drying characteristics: The drying mechanism depends on simultaneous heat and mass transfer phenomenon and factors dominating each process determined the drying behavior of the product (Dulawat *et al.*, 2012; Garg and kumar, 2000). The drying rates were computed from the experimental data and drying characteristics curves i.e. moisture ratio (db) vs. time, drying rate vs. time and moisture content (db) were plotted.

Determination of moisture content: The initial moisture content of the sample was determined by the hot air oven drying method as recommended by (Ranganna, 1986). Samples were weighed using the electronic weighing balance of least count 0.01g. The samples of sprouted moth beans were placed in a hot air oven at 70 ± 0.5° C for 12.00 h and following formulae were used (Bala, 2016).

$$M\ (wb)\ \% = \frac{w_1 - w_2}{w_1} \times 100 \quad (1)$$

$$M\ (db)\ \% = \frac{w_1 - w_2}{w_2} \times 100 \quad (2)$$

where,

M = moisture content, %
w_1 = weight of sample before drying, gram
w_2 = weight of bone dried sample (bdm), gram

Determination of moisture ratio: The Moisture ratio of the produce was computed by following formula (Chakraverty, 1988).

$$M.R = \frac{M - M_e}{M_o - M_e} \quad (3)$$

where,

M. R = moisture ratio
M = moisture content (db), %
M_e = equilibrium moisture content (db), %
M_0 = initial moisture content (db), %

The drying rate of produce sample during drying period was determined as follows (Chakraverty, 1988).

$$\text{Drying rate } (D_R) = \frac{\Delta W}{\Delta t} \quad (4)$$

where,

ΔW = weight loss in one h interval, gm/100gm bdm min
Δt = difference in time reading, min

Drying efficiency (ŋ): The drying efficiency of solar tunnel dryer is the ratio of heat gained to the heat input. The heat input was calculated by considering total solar radiation incident in aperture area of solar tunnel drier during total drying hours in the day. (Prasad *et al.,* 2006)

$$ŋ, \% = \frac{M \times \lambda}{I_{AC} \times A \times t} \times 100 \quad (5)$$

where,

η = drying efficiency, %
M = mass of water evaporated, kg
λ = latent heat of vaporization, MJ kg^{-1}
I_{AC} = total solar radiation, MJ m^{-2}
A = collector area, m^2
t = time, s

Economic analysis of solar tunnel dryer: Economic analysis of solar tunnel dryer was calculated by using economic indicators *viz.*, net present worth (NPW), benefit-cost ratio (B/C ratio) and payback period as discussed by Manjarekar and Mohod (2010) .

The following assumptions/considerations were taken for carrying out an economic analysis of solar tunnel drying system.

- Area of the solar tunnel dryer was 18.0 $m^{2.}$
- The capacity of solar tunnel dryer for sprouted moth beans was 100 kg $batch^{-1}$
- Dryer produce 42 kg dried product.
- Number of batches performed in the STD and open sun drying (Jan to May).
- The initial cost of the Sprouted moth beans Rs. 50 kg.
- Discounting rate was assumed to be 10% as compared to bank lending rate of interest.
- Cost dried product of sprouted moth beans was Rs.150/kg.
- Annual repair and maintenance cost was Rs.10,000 considering replacement of UV sheet after 3 years and expenditure towards painting etc.

RESULTS AND DISCUSSION

An evaluation of solar tunnel dryer was carried out at no load and full load condition in clear sunny days. The dryer had four compartment/layer namely Top (A), Middle (B), Middle (C) and Bottom (D). Therefore the temperature in each compartment was recorded separately and mentioned.

No load testing of a solar tunnel dryer: The variation of temperature, relative humidity of different locations inside the solar tunnel dryer with corresponding ambient temperature, relative humidity was recorded to evaluate the performance of solar tunnel dryer at no load condition during the season (Oct. 2014).

The maximum peak temperature of 62 ºC recorded inside the solar tunnel dryer at 13:00h with corresponding ambient temperature, relative humidity and solar radiation of 34.7 ºC, 27%, and 950W/m², respectively as shown in Fig 3. It was also observed that the maximum temperature inside the solar tunnel dryer was found to be in top tray (62 ºC) and bottom (61ºC) tray at 13:00h.

The maximum value of relative humidity of 38% was observed at 9:00h and found to be decreased with increased in temperature and day time. The minimum value of relative humidity was 10% recorded at 13:00h and remained constant up to 17:00h during the no load test as shown in Fig 4.

Full load testing of a solar tunnel dryer: The samples of the sprouted moth beans were loaded in a thin layer on trays over racks in the STD. The drying of these samples was continued until the moisture content reached to equilibrium moisture content (EMC) of the selected products on a dry basis. The drying experiments were carried out in the month of October.

The maximum temperature inside the solar tunnel dryer (day 1) achieved its peak value 58ºC at 13:00h of the day corresponding to top 58 ºC and bottom 57.5 ºC with corresponding ambient temperature 34.2ºC and relative humidity 38% and solar radiation 980W/m², respectively as shown in Fig 5. The minimum temperature of 35 ºC was achieved at 9:00 with corresponding top 37 ºC and bottom 36 ºC with ambient temperature 29.2 ºC, ambient relative humidity 59% and solar radiation 400W/m². Therefore, it is concluded that the temperature inside the solar tunnel dryer varied from 35 ºC to 58 ºC. Sprouted moth beans samples took two days to reached the equilibrium moisture content, hence the observation such as temperature and relative humidity were recorded for the both days, Fig 5 and 6. Once STD samples were dried, the observation had not recorded further.

From Fig 6, it could be revealed that the minimum relative humidity of 12% was observed inside the solar tunnel dryer achieved at 14:00h of the day 1 with corresponding ambient temperature 36.4ºC, ambient relative humidity 27% with solar radiation 860W/m². The maximum relative

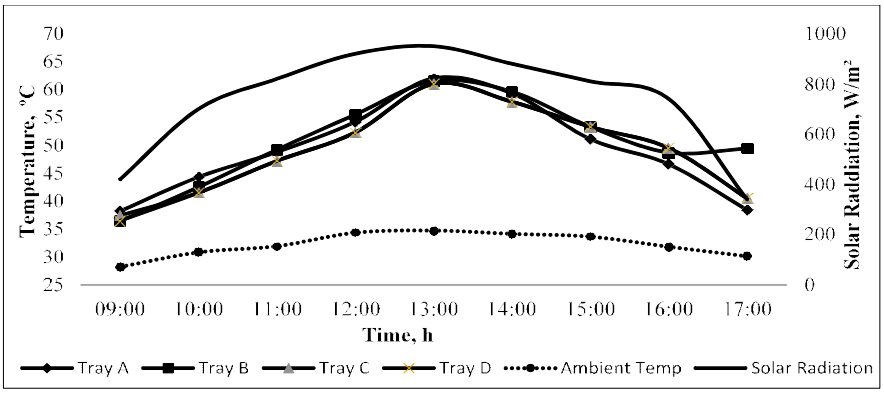

Fig 3: Variation in average temperature during no load test in STD.

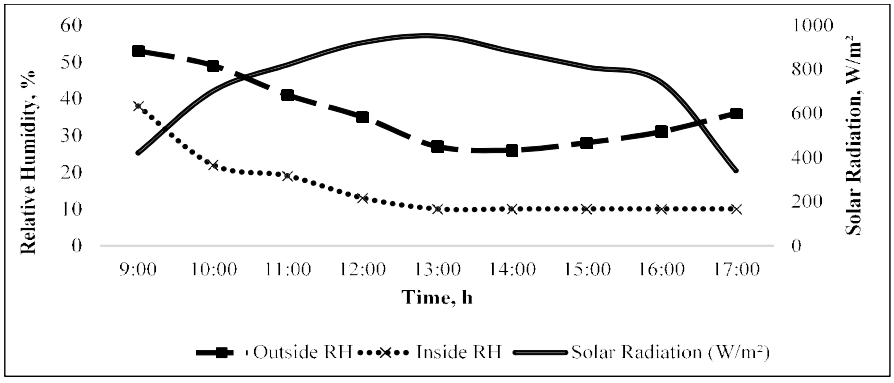

Fig 4: Variation in relative humidity during no-load test in STD.

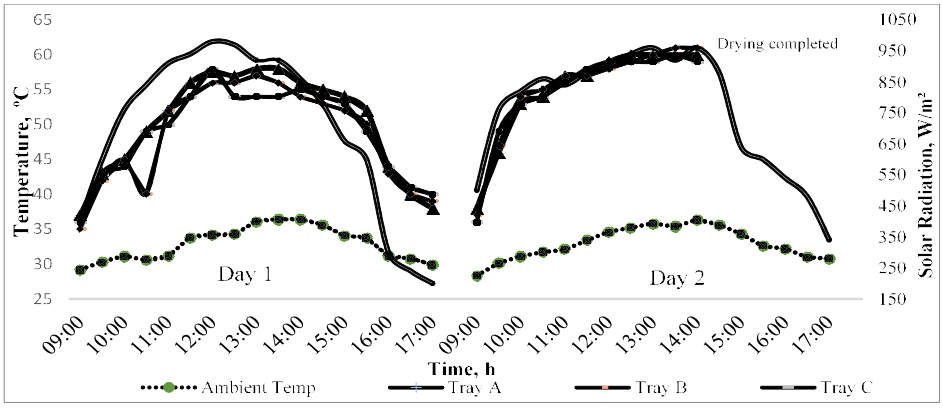

Fig 5: Variation in average temperature during full load test in STD.

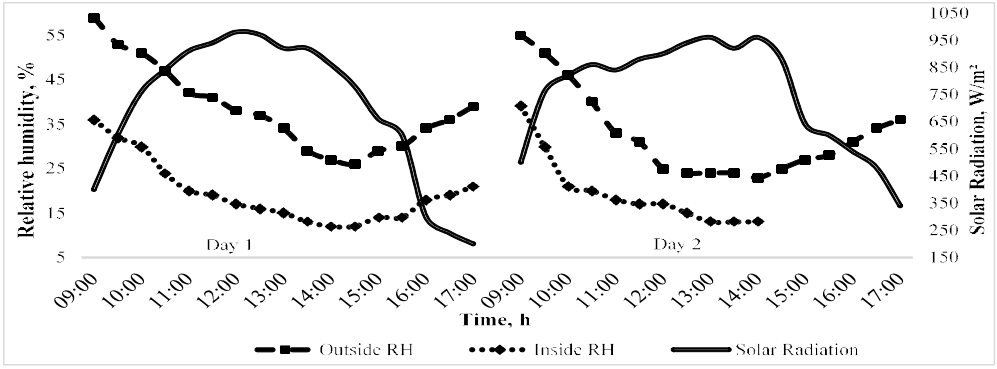

Fig 6: Variation in relative humidity during full load test in STD.

humidity inside the solar tunnel dryer was found to be 36% at 9:00h of the day with corresponding ambient temperature 29.2ºC, ambient relative humidity 59%, and solar radiation 400W/m².

Drying characteristics of sprouted moth beans in OSD and STD: The drying characteristics of sprouted moth beans samples in natural convection solar dryer were studied and compared with open sun drying. The different drying characteristics in terms of moisture content (db), drying rate (gram/100gram of bone dry mass min) and moisture ratio were studied.

Drying of Sprouted moth beans in STD and OSD: The average moisture content (db) of sprouted moth beans sample was reduced from 177.778 to 16.667% and 17.77% (db) in 13.5h and 16.5h in STD and OSD, respectively (Fig 7 and 9). Similarly, it was observed that the maximum moisture removal had taken place as 177.77 to 64.44 % (db) up to 8h during the first day of drying.

From Fig 8 and Fig 10, it was observed that the drying rate varied from 0.4197 to 0.001372 g/100g bdm min and 0.3518 to 0.001684 g/100g bdm min for drying of sprouted moth beans in solar tunnel dryer and open sun drying, respectively. The average drying rate was found to be 0.01519 and 0.0074 g/100g bdm min corresponding to average moisture ratio of 0.4160 and 0.4236 for STD and OSD, respectively.

The results of the studies were found to be parallel on similar studies conducted on solar tunnel dryer conducted by Sengar *et al.,* (2018) for green leaves, Arjoo *et al.,* (2017) for various vegetables, Fudholi *et al.,* (2014) for red chili, Prakash and Satyanarayana, (2014) for Guntur chili, Dhanore and Jibhakate, (2014) for red chili, Mastekbayeva *et al.,* (1998), Thakre *et al.,* (2016), and Nagarajan and Prem Kumar, (2014) on various agricultural products.

Drying efficiency (η): Overall drying efficiency of sprouted moth beans in STD was determined by considering the heat gained and heat utilized by the product in STD. The overall efficiency of sprouted moth beans samples dried in solar tunnel dryer was found to be 19.77% and it was associated with total drying hours and heat input by solar energy in STD, Table 2. The total drying hours, average moisture removed and average heat input for sprouted moth bean sample were found to be 13.5h, 58 kg, and 368315 kJ/m², respectively.

However, in similar studies conducted on solar tunnel dryer by (Arjoo *et al.,* 2017) reported the drying

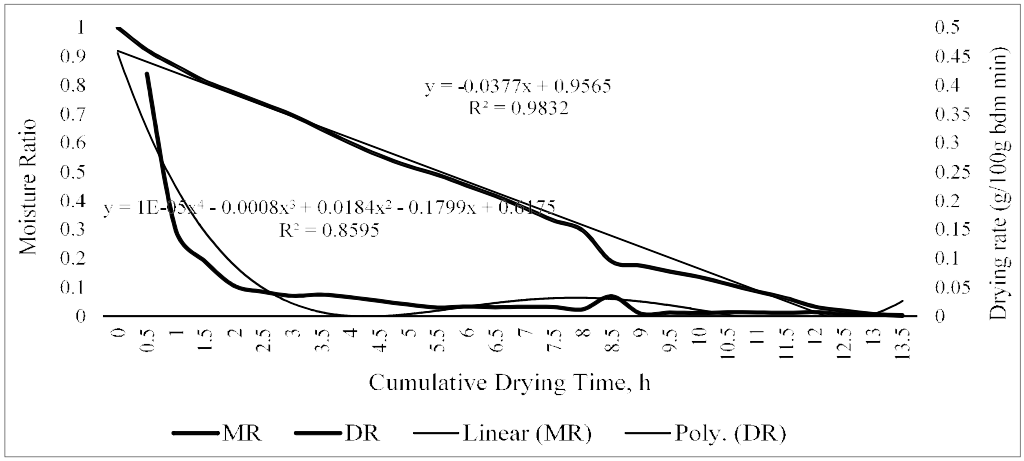

Fig 7: Variation of moisture ratio and drying rate of Sprouted moth beans in STD.

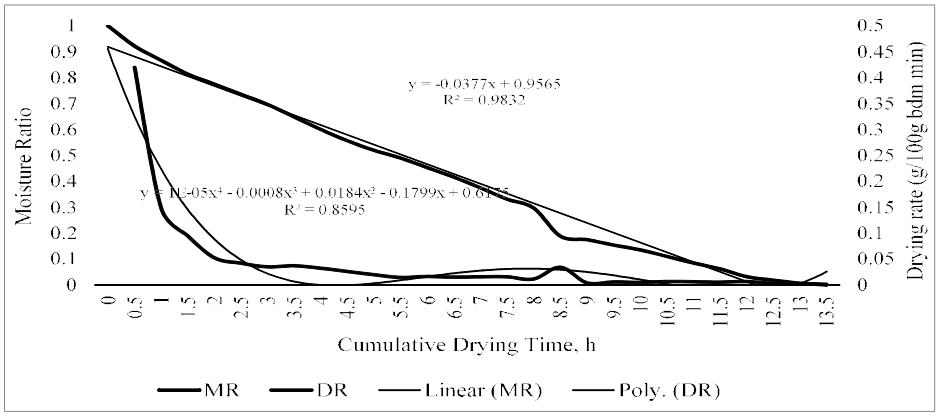

Fig 8: Variation of Moisture Content of Sprouted moth beans in STD.

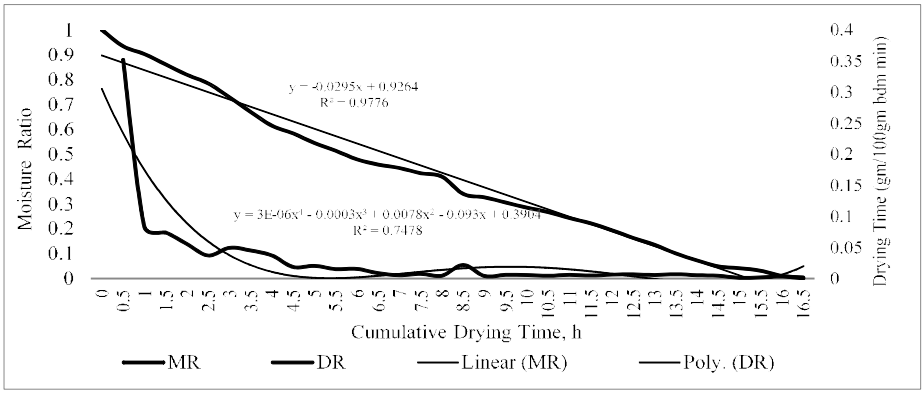

Fig 9: Variation of moisture ratio and drying rate of Sprouted moth beans in OSD.

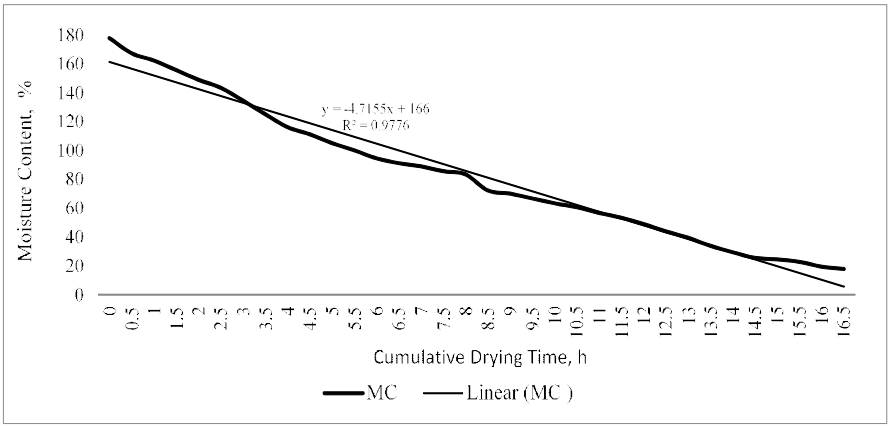

Fig 10: Variation of moisture content of sprouted moth beans in OSD.

Table 2: Overall Efficiency of STD.

Sample	Total drying time, s	Avg. moisture removed, kg	Avg. Solar Radiation, kJ/m²	Efficiency, %
Sprouted moth beans	48600	58	36831.5	19.77

Table 3: Economic analysis of STD.

Description	sprouted moth beans
Initial investment (Rs)	55000
Annual use no. of batches	75 each 100kg
Cost of raw material (Rs yr^{-1})	Rs.50/kgTotal = 3,75,000
Cost of labor for drying (Rs yr^{-1})	10,000.00
Operation and maintenance cost (Rs yr^{-1})	3000.00
Total dried product (kg)	3150
The total cost of the finished product	@Rs.150/kg 472500
Economic Indicators	
Net present worth, Rs.	583910.68
Benefit- cost ratio	1.19
Payback period	15 month 8 day

efficiency between 8.89% to 17.63% for various vegetables and (Dhanore and Jibhakate, 2014) reported approx. 24 % for red chilli.

Economics of STD for drying of sprouted moth beans: The economic feasibility of the solar tunnel dryer for the drying of above sample was calculated by considering the initial investment of the dryer, average repair and maintenance cost, cost of raw material and selling market price of the material after drying. Based on the study average parameter were calculated for economic analysis of different samples depicted in Table 3.

CONCLUSION

It was concluded from the results that, the temperature inside the solar tunnel dryer was boosted up by 15-20°C more than the ambient temperature. The moisture content of given samples was reduced exponentially with drying time and the total drying time required for the drying of samples was saved using the improved method of drying (STD) and was found to be 17.64% in comparison with open sun drying for sprouted moth beans. The overall drying efficiency of sprouted moth beans was found to be 19.77%. It was also observed that the solar tunnel dried samples were found to be of good quality in terms of color, taste, and aroma

as compared to open sun-dried samples. The benefit-cost ratio, net present worth and payback period for Sprouted moth beans were found to be 1.19, Rs. 583910.68 and 15 months 8 day, respectively. Thus, solar tunnel dryer can be proposed as a suitable alternative to the local drying method of selected products.

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