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Techno-Economic Evaluation of Solar Tunnel Dryer for Drying of Basil (*Ocimum sanctum*)

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A B S T R A C T

A solar tunnel dryer installed at Ramakrishna Agro. Vegetables & Food Product Kodoli, was evaluated. Its performance for Basil leaves drying and also its techno-economic analysis was carried by different indicators such as Net Present Worth (NPW), Benefit-Cost ratio (B:C) and Payback Period. The maximum temperature of 61ºC was recorded at 13:30 h in solar tunnel dryer during the drying process which was 40.49% (36.3ºC) higher than the maximum ambient temperature at the same time. On an average, a total drying time of 12.5 hours were required for solar tunnel dryer to reduce the moisture content of Basil leaves from initial value of 1011.11 percenton dry basis (d.b) to a final moisture content of 33.33 per cent (d.b) while the open sun drying required on an average 15.5 drying hours to obtain same level of moisture content. The Net Present Worth, Cost-benefit Ratio and Payback period for solar tunnel dryer were Rs. 62,894/-, 1.11 and 7 Month 2 Days, respectively.

Introduction

Basil (*Ocimum Sanctum*) is a popular culinary and medicinal herb from ancient time until now also called as holy basil or Basil. The uses of basil are varied and plentiful in its fresh form in food preparation; it is used with vegetables, meat, fish, sauces, stews, dressings, herbal teas, liqueurs, and mixed drinks i.e. flavouring from their strong spicy aroma But it is basil's medicinal properties, rather than its culinary value, that extend the herb's uses and it has innumerable medicinal applications ranging from treating mundane coughs and colds effectively to rendering poisoning inactive (Rajput., 2012). It has also other important medicinal properties such as antioxidant, anti-inflammatory, antiviral or anti-microbial properties. Basil is considered to be adaptive balancing different process in the body and helpful for adapting to stress. It contains Vitamin A, C, and minerals like calcium, zinc, iron as well as chlorophyll and many others. Phytonutrients also enhance the efficient digestion and use of nutrients from the uses of food and other herbs (Bhateja*et al.*, 2012).

Basil powdered as many benefits as follows, relieve stress, acts as an adaptogen, bolsters immunity, enhances stamina, provide support during the cold season, promote healthy

metabolism, natural immune modulator. Basil powdered is also used for the preparation of tea which is caffeine free and safely consumes up to six times a day. For more benefits increase the ratio of Basil powder to water steep longer. The powder also found to cause a reduction in fasting blood sugar and postprandial glucose level in patients. The basil plant is scarce during offseason, which necessitates good preservation, also the plant is highly perishable and has to be preserved against deterioration and spoilage so drying is proposed.

Drying is the most widely used primary method of food preservation. The green color of Basil leaves is due to the chlorophyll. The most common change occurs in the green colour vegetables during the thermal processing is the conversion chlorophyll to the pheophytin, causing a colour change from bright green to olive-brown, which is undesirable to consumer for a green vegetables, pre-treatment prior to the drying can aid the chlorophyll to retain during the drying operation (Kalbande *et al.,* 2016). Traditionally, the food products are dried by spreading in open sun in a thin layer. Though this method is economical and simple, it has the drawbacks like; no control over the rate of drying, non-uniform drying, chances of deterioration due to exposure of products against rain, dust, storm, birds, rodents, insects and pests which results in poor quality of dried products (Rathore *et al.,* 2010; Assefa *et al.,* 2010). In open sun drying the losses of valuable properties of Basil take place, so retain that valuable property tunnel drying is preferred (Kumar *et al.*, 2017).

Materials and Methods

The experiment was carried at solar tunnel dryer installed at *Ramakrishna* Agro. Vegetables and Fruit Products, *Kodoli, Tal–Panhalla,* Dist- *Kolhapur,* By CAET DR. P. D. K. V. Akola. Its technical specifications are given in Table 1.

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 *et. al* 2012). 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 S. 1986). Samples and weighed using electronic weighing balance of least count 0.01g. The samples Basil were placed in a hot air oven at 70 ± 0.5^0 C for 12.00 h and Following formulae were used (Bala, 2016).

$$M.C.(db)\% = \frac{(W_1 - W_2)}{(W_2)} \times 100$$

Where,
W_1=Weight of the sample before drying,
W_2= Weight of bone dried sample

Determination of moisture ratio

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

$$Moisture Ratio\,(M.R.) = \frac{(M - M_e)}{(M_0 - M_e)}$$

Where,

M = Moisture content (db), per cent
M_e = EMC, (db), per cent
M_0 = IMC, (db), per cent

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

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

Where,
ΔW = Weight loss in one h interval (gm/100gm bdm min.)
Δt = Difference in time reading (h)

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)

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

Where,
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, sec.

Economic analysis of solar tunnel dryer

Economic analysis of solar tunnel dryer was calculated by using economic indicators Viz., Net present worth (NPW), the benefit-cost ratio (B/C ratio) and payback period.

The following assumptions/considerations were taken for carrying out an economic analysis of solar tunnel drying system. The area of the solar tunnel dryer was18.0 m^2, capacity of the solar tunnel dryer for basil leaves was 25 kg $batch^{-1}$, the dryer produce 2.5Kg dried product of basil leaves, the initial cost of the basil leaves Rs.25 kg., discounting rate was assumed to be 10 per cent as compared to bank lending rate of interest, cost dried product of basil powder was Rs.850 Kg, the 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

Testing of solar tunnel dryer was carried at no load and full load condition on clear sunny days (Fig. 1 and 2).

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 winter season (Oct.2014).

Figure 3 showed that during the monsoon season, the maximum peak temperature inside the solar tunnel dryer with respect to time achieved its peak value at 13:00 h. was found to be 62ºC with corresponding ambient temperature, relative humidity and solar radiation of 34.7ºC, 27 per cent and 950 W/m², respectively. It was observed that the maximum temperature inside the solar tunnel dryer was found to be 62ºC followed by top (62ºC) and bottom (61ºC) tray at 13:00 h.

Figure 4 showed that minimum relative humidity inside the solar tunnel dryer was found to be 10 per cent and its peak value at 13:00 h and maximum relative humidity inside the tunnel dryer was found to be38 per cent and it was achieved at 9:00 h

Full load testing of a solar tunnel dryer

The samples of the basil leaves were loaded in a thin layer on trays over racks in the solar

tunnel dryer. The drying of these samples was continued till the moisture content reached to EMC of the selected products on db. The drying experiments were carried out in monsoon season in the month of October.

Figure 5 revealed that the maximum temperature inside the solar tunnel dryer achieved its peak value 61ºC at 13:30 h of the day-3 corresponding to top 61ºC and bottom 55ºC with corresponding ambient temperature 36.3 ºC and relative humidity 30 per cent and solar radiation 940 W/m², respectively. The minimum temperature 32ºC was achieved at 9:00 h with corresponding top 40ºC and bottom 32ºCwith corresponding ambient temperature 30.1ºC with ambient relative humidity53 per cent and solar radiation 640 W/m². Thus the temperature inside the solar tunnel dryer varied from 32ºC to 61ºC.

From figure 6 revealed that the minimum relative humidity inside the solar tunnel dryer achieved its peak value 12 per cent at 15:30hr of the day corresponding to the ambient temperature 32.2ºC, ambient relative humidity 25 per cent with solar radiation 600 W/m². The maximum relative humidity inside the solar tunnel dryer was found to be 28per cent at 9:00 h of the day with corresponding ambient temperature 30.1ºC, ambient relative humidity 53 per cent and solar radiation 640W/m².

Drying characteristics of basil leaves in open sun drying and solar tunnel dryer

The drying characteristics of basil leave samples in natural convection solar dryer was studied and compared with open sun drying. The different drying characteristics in terms of moisture content per cent (db) drying rate (gm /100 gm bdm min) and moisture ratio were studied.

Drying of basil leaves in STD and OSD

From figure 7 and 9 revealed that the average moisture content per cent (db) of Basil leaves inside and outside sample was reduced from 1011.11 to 33.33 per cent and 33.33 per cent from (db) in 12.5 h and 15.5 h in solar tunnel dryer and open sun drying, respectively. Similarly, it was observed that the maximum moisture removal had taken place from 1011.11 to 262.96 per cent and 400per cent (db) up to 8 h during the first day of drying.

Table.1 Technical specification of STD

Particulars	**Specifications**
Aperture area, m2	24.25
Width of dryer, m	3.00
Length of dryer, m	6.00
Drying tray area, m2	2.5 (1.6 m x 1.6 m)
Number of trays	05 on each trolley
Number of trolleys	2 Nos., (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, m2	0.05
Exhaust Fan, single phase, 40 Wp, 1400 rpm	1Nos, Brushless AC
Door	1.80 m x 0.75 m

Table.2 Overall efficiency of STD

Sr. No.	Sample	Total drying time, (sec)	Avg. moisture removed,(kg)	Avg. Solar Radiation, (kJ/m^2)	Efficiency, (%)
1	Basil	45000	88	31950	34.58

Table.3 Economic analysis of STD

Sr. no.	Description	Basil leaves
1	Initial investment (Rs)	55000
2	Annual use no. of batches	80(25Kg)
3	Cost of raw material (Rs yr^{-1})	@25Kg 50,000
4	Cost of labour for drying (Rs yr^{-1})	10,000.00
5	Operation and maintenance cost (Rs yr^{-1})	3000.00
6	Total dried product (kg)	100
7	Total cost of finished product	@Rs850/kg 85000
	Economic Indicators	
A	Net present worth, Rs	62894.23
B	Benefit- cost ratio	1.11
C	Payback period	7 month 2 day

Fig.1 Schematic view of a solar tunnel dryer

Fig.2 Process flow chart of Basil

The fresh product was chosen for the experiment of Basil and the following process are done.

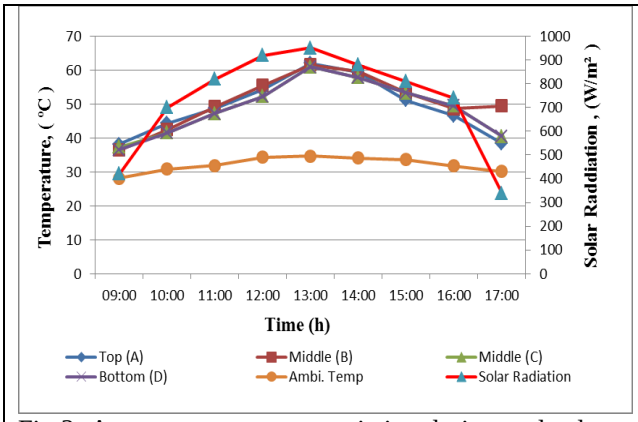

Fig 3: Average temperature variation during no load test in STD

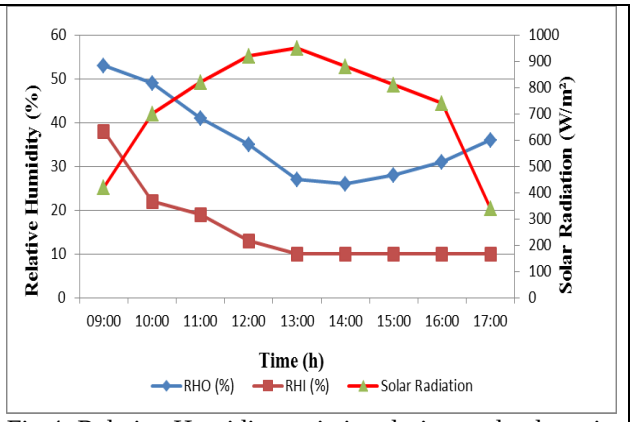

Fig 4: Relative Humidity variation during no load test in STD

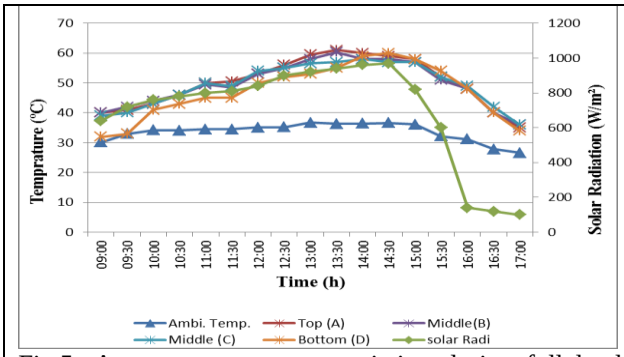

Fig.5: Average temperature variation during full load test in STD

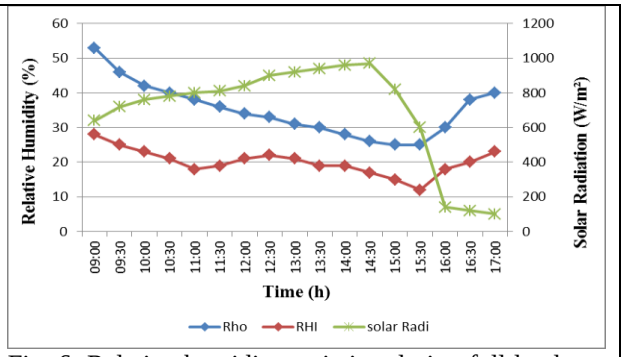

Fig. 6: Relative humidity variation during full load test in STD

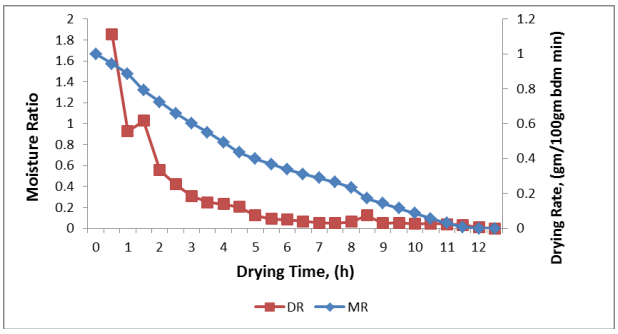

Fig.7: Variation of moisture ratio and drying rate of Basil leaves in STD

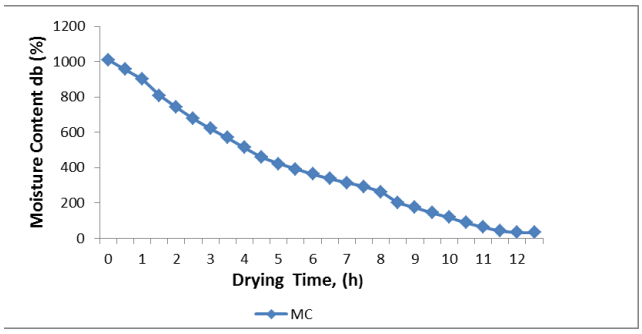

Fig.8: Variation of Moisture Content of basil leaves in STD

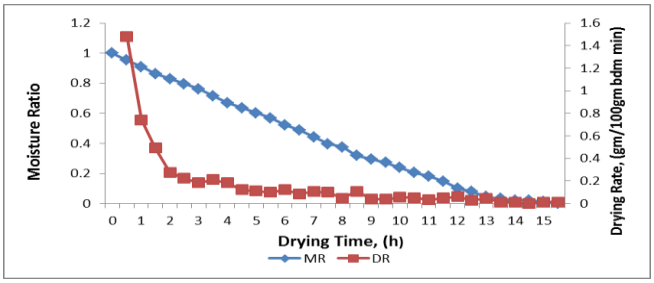

Fig.9: Variation of moisture ratio and drying rate of Basil leaves in OSD

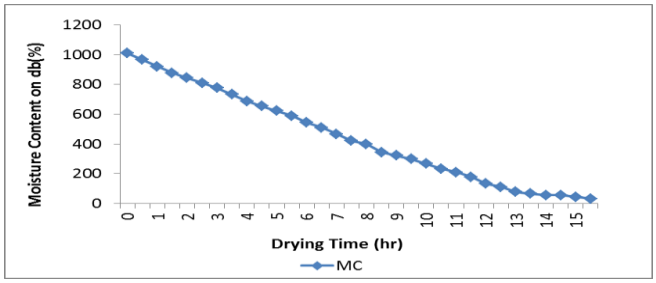

Fig.10: Variation of Moisture Content of basil leaves in OSD

From figure 8 and 10 revealed that the drying rate varied from 1.8518 to 0.010288gm/100gm bdm min and 1.4814 to 0.01194gm/100gm bdm min for drying of basil in solar tunnel dryer and open sun drying, respectively. The average drying rate was found to be 0.1234 and 0.10582gm/100gmbdm min corresponding to average moisture ratio of 0.3977 and 0.4431 for STD and OSD, respectively.

Drying efficiency (ŋ)

Overall efficiency for drying of basil leaves in STD was determined by considering the heat gained and heat utilized by the product in STD.

The overall efficiency of a solar tunnel dryer

The overall efficiency of solar tunnel dryer based on experimental data was calculated by considering the total moisture evaporated associated with heat input and heat gain by-product. The results obtained from overall efficiency of basil leave dried in solar tunnel dryer are depicted in Table 2.

It is revealed from Table 2 that the overall efficiency of Basil samples dried in solar tunnel dryer in monsoon season was found to be 34.58 per cent. The overall efficiency is associated with total drying h and heat input by solar energy in STD. The total drying h, avg. moisture removed and avg. heat input for basil sample was found to be 12.5 h, 88 kg, 31950 kJ/m², respectively

Economics of solar tunnel dryer for drying Basil Leaves

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 price of the material after drying. Based on the study average parameter were calculated for economic analysis of different samples depicted in Table 3.

It is concluded from the results that at no load test, the avg. temperature and relative humidity during daytime in the STD were 50.67°C and 15.77 per cent and in OSD was 32.16 °C and 36.22 per cent, respectively. It was observed that in full load test avg. temperature and relative humidity during daytime STD were 47.58° C and 19.70per cent in OSD was 32.32°C and 33.41 per cent in the month of October. Solar tunnel drying took 12.5 h for Basil to bring down the moisture content from 1011.11 to 33.33 per cent (db) and 16 h under open sun drying. The overall drying efficiency of basil leaves and was found to be 34.58 per cent. The benefit-cost ratio, net present worth and payback period for basil leaves were found to be 1.11.Rs. 62894.23 and 7 months 2 day.

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