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Feasibility of Poly House Solar Bulk Drying System for Turmeric (*Curcuma longa*) in Humid Condition of North-East India

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ABSTRACT

North-East India (NEI) annually produces 110.68 thousand tonnes of quality turmeric, which is around 10% of national production. Freshly harvested turmeric is spoiled in one week at an ambient temperature from 27 to 30^{0}C. Considering the climatic condition of the region, the present study explored the feasibility of an environment-friendly drying system for storage and value addition. Poly-house Solar Dryer (PSD) is one of the cost-effective, bulk drying systems, among various systems for minimal processing of turmeric at the farm level. The existing structural design dimensions were improvised and the system automated to attain higher hot air circulation and thermal efficiency. The structural system is standardized from segmented to a hemi-cylindrical section of span 10.2 m and radius 2 m, capacity 1000 kg (with racks), moisture reducing silica gel embedded passive dehydrators during the night at air inlets, insulated heat storage and rubber cladding for air outlets. A preliminary trial under no load test exhibited that the system generated hot air ranging from 42.70 to 54.32° at an ambient temperature of 28.50 to 34.60°C. Sliced turmeric dried in 22 to 23 h in February. The initial and final moisture content of turmeric ranged from 78-89% to 10-11% (wb), respectively. At an average solar radiation of 521.46 watt/m^2, the thermal efficiency of the dryer was 24.89%. After testing several thin layer drying models, the Page model proved to be the most accurate when simulation was performed on all of the drying data.

Key words: Poly house solar dryer, embedded sponge, thermal efficiency, bulk drying, solar radiation

INTRODUCTION

Turmeric has been gaining more economic importance because of its medicinal properties against the pandemic, COVID 19 (Gupta *et al.*, 2020). North-East India (NEI) produces 110.68 thousand tonnes of turmeric per year (GOI Horticultural Statistics, 2018). Turmeric has cultural relevance in skin care, and its uses in dermatology or cosmetic industry (Gopinath and Karthikeyan, 2021). The most commonly used method to preserve turmeric fingerling and rhizome in developing countries is open sun drying (Jeevarathinam and Pandiarajan 2016). In North East India 70% of local production lacks minimal processing and storage facilities at the farm, non-existence of an organized marketing system, forces the growers to sell their produce fresh just after harvesting through commission agents.

Infrared hot air drying of 2 kg sliced turmeric at 600C with an air velocity of 2 m/sec produces better-dried quality (Jeevarathinam et al., 2021). Dehydration by hot air, vacuum infrared and vacuum microwave of orange slices was studied by Bozkir (2020). From the review of the literature, it can be stated that the open sun drying method could result in the loss of volatile oil up to 25%. Most developed solar dryers are of size less than 100 kg but now there is need of bulk dry turmeric for cosmetic industry. As such present study was taken up to develop an improvised, automated Poly-house Solar Dryer (PSD) for bulk drying of turmeric and to evaluate drying kinematic of turmeric in Poly-house solar dryer.

MATERIALS AND METHODS

Typical climatic conditions of NEI are marked by high relative humidity almost throughout the year. June to Sept are the wettest months and January to March is the driest part of the year (World Data dot., 2023). In North-East India pineapple, litchi, ginger and turmeric are grown under natural condition in large areas having high genetic diversity (De, 2017). Maisanam *et al.* (2018) reported that throughout NEI

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average solar radiation level was above 600 W/m^2 and freshly harvested turmeric was ready for minimal processing in the months of January to February and was away from the wettest part of the year (June-July).

Fabrication of Poly-house solar dryer was carried out in Instructional-cum-Research farm of Assam Agricultural University, Jorhat under the meteorological conditions of Assam (latitude of 26.39°N; longitude of 78.03°E) in NEI. In the project site average relative humidity and temperature during February-March vary from 55. to 90% and 24° to 32°, respectively. During this period there is high relative humidity (around 90%) in early morning hours (2 to 4 A. M.).

During experimentation, Delta SPN1 Sunshine Pyranometer (LP PYRA 03) coupled with a digital data logger was used to collect solar insolation data to analyze thermal energy available in watt/m^2. Calibrated electronic temperature and humidity sensors with data loggers were used to find out the temperature and relative humidity of air at different locations inside the dryer and ambient conditions, respectively.

Physico-chemical properties of turmeric for minimal processing were evaluated in this study. Out of 10 samples, the average diameter and length of turmeric fingerling were found to be 15.00 and 63.80 mm, respectively. Turmeric was washed to clean the debris and dirt followed by blanching in hot water for 15-20 min.

Based on the review of literature by Saravanapriya and Mahendiran (2017), a Poly-house dryer was conceived for design with the following features. Fresh air inlets, hot air outlets (chimney) with rubber cladding for natural convection, forced air outlets (exhaust fans) for forced convection and easy access for loading and unloading suitable for bulk loading. In the design of the Poly-house dryer following criteria of the drying system were considered bulk drying facility, cost effective automation, better heat storage capacity and low cost of construction and operation (Table 1).

Table 1. Assumptions of parameters to carry design calculation

Parameters	Value
Quantity of material to be dried	650-1000 kg
Initial moisture content of the product	85%
Final moisture content of the product	10.5%
Effective drying period	42 h
Initial temperature of the product	27°C
Maximum permissible temperature of the product	60°C
Latent heat of vaporization of water	L=2260 kJ/kg
Specific heat of water, Cpw	4.186 kJ/kg/K

Different nomenclatures used are given in Table 2.

Table 2. Nomenclature used in poly house

Mass of water vapour (kg)	
M_p	Mass of product (kg)
m_i	Initial moisture content (% db)
m_f	Final moisture content (% db)
M_wE_a	Energy gain from air (KJ)
I_c	Solar intensity (W/m^2)
A_c	Area of collector (m^2)
η_c	Efficiency of collector (%)
m_a	Mass flow rate of air (kg/sec)
C_a	Specific heat of air (KJ/kg/°C)
C_d	Specific heat of product, (KJ/kg/°C)
C_p	Specific heat of water (KJ/kg/°C)
ΔT	Temperature difference
q	Total energy required for drying of selected product (KJ)
M_d	Mass of product after drying (kg)
M	Mass of initial water content (kg)
λ	Latent heat of vaporization of water (KJ/kg)
T_1	Ambient air temperature (°C)
T_1	Ambient air temperature (°C)
D_R	Drying rate
t	Drying time (hr)
η_{th}	Dryer efficiency (%)
V	Volume of drying chamber (m^3)
h	Height of dryer from base (m)
r	Radius of hemi-cylindrical tunnel dryer (m)
l	Length of square window (m)
A_i	Area of air inlet (m^2)
A_0	Area of air outlet (m^2)
Q_i	Volumetric flow rate of air inlet (m^3/sec)
Q_o	Volumetric flow rate of air outlet (m^3/sec)
v_i	Velocity of air inlet (m/sec)
v_o	Velocity of air outlet (m/sec)
T_f	Time taken to fill the drying chamber (sec)
T_e	Time taken to empty the drying chamber (sec)
R_t	Residence time (sec)

Various parameters were computed as:

Volumetric flow rate of air inlet: $Q_i = A_i v_i$ ...(1)

Time taken to fill the drying chamber: $T_f = \dfrac{\pi r^2 h}{2A_i v_i}$ ...(2)

Volumetric flow rate of air outlet: $Q0 = A_0V_0$ ...(3)

Time taken to empty the drying chamber: $T_e = \dfrac{\pi r^2 h}{2A_i v_0}$ ...(4)

$$\text{Residence time: } R_t = \frac{1}{2}\;\frac{\pi r^2 h}{A_0 v_0 - a_i v_i} \quad \dots (5)$$

The design components and dimensions of the solar tunnel dryer are summarized in Table 3 and the constructed dryer is shown in Fig 1.

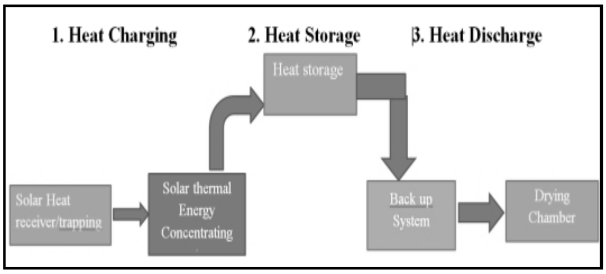


Fig. 1. Pictorial representation of the drying system.

The area of the base structure is such that 0.5 to 1.0 t of fresh turmeric can be dried in one batch. In drying vertical space was also utilized by using racks. Commercially available untested pipes were bent in such a way that the semi-circular-shaped skeleton of the tunnel was prepared (Fig. 2).

Orientation of the solar tunnel dryer was set in the east-west direction, to obtain maximum solar radiation throughout the day. With the least exposure to solar radiation, the northern wall of the solar tunnel dryer was found to be the most vulnerable point for heat loss (Chauhan and Kumar, 2016). In the northern wall, insulation was provided from the inside using a polystyrene sheet to a height of 600 mm from the dryer floor.

The moisture removal rate of the samples was measured at an interval of 2 h. A mechanical balance was used to measure the weight of the total batch and the readings were obtained at the beginning and end of the drying. The experiments were conducted to standardize the PSD from January to April under the meteorological conditions of North-East India. This dryer was multi-functional and tested for drying products like ginger, Indian Gooseberries and Elephant apples of similar batch capacity, respectively (Naik *et al.*, 2016). Thermal efficiency of the solar tunnel drier was estimated using the Equation 6.

$$\eta_{th} = \frac{mw \times hfg}{A \times 1} \quad \dots (6)$$

Where, η_{th} – drier thermal efficiency, m_w – the mass of water evaporated in time t = (mi - mf) kg, hfg – the latent heat of vaporization of water (kJ/kg), A, – the area of solar tunnel drier in m^2 and I – Solar intensity in W/m^2.

In the thin layer drying experiment of turmeric in PSD, the moisture ratio (MR) of turmeric slices was calculated using the formula:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \dots (7)$$

Where M – Moisture content % (w b) of turmeric at time t, M_e – Equivalent moisture content % (w b) of turmeric and M_0 – Initial moisture content of the material % (w b).

Effective moisture diffusivity for drying agricultural products in thin slab may be written as

$$MR = \frac{8}{n^2} \exp \frac{D^{eff}}{4h^2} \quad \dots (8)$$

The turmeric drying practical was long, taking n=0 the equation was written as:

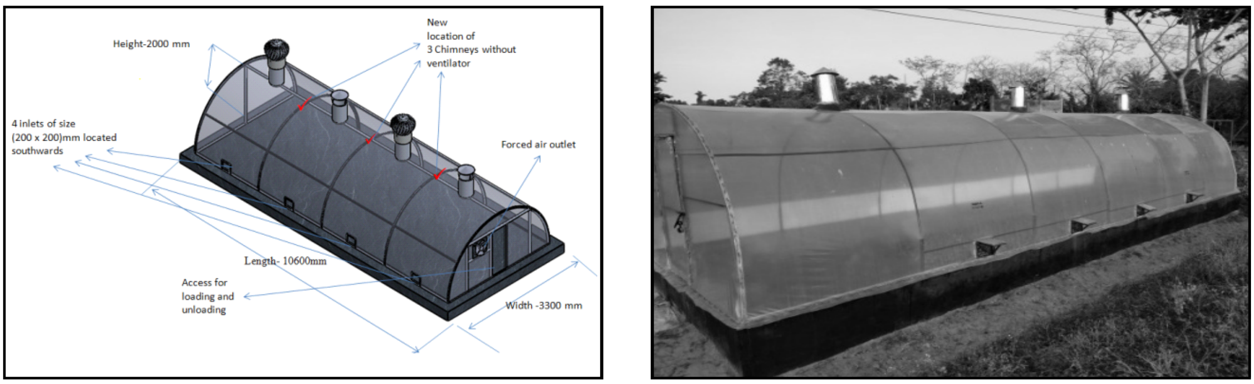


Fig. 2. Schematic view and constructed dryer.

$$A = \frac{8}{\pi^2} \text{ for slab thickness, K}$$

Putting in linear form

$$\ln (MR) = \frac{M - M_e}{M_0 - M_e} = \ln A - kt \qquad ...(9)$$

A straight line with a slope "k" was obtained by plotting ln (MR) against drying time. Now considering that drying occurred from the top as well as from the bottom parallel faces, with thickness of thin layer assumed to be half the thin layer thickness $t_{\text{thin layer}}$, where, h = $t_{\text{thin layer}}/2$ expressed in "m." . Hence effective moisture diffusivity of turmeric was calculated as:

$$K = \frac{\pi^2 D_{eff}}{4h^2} \qquad ...(10)$$

Bulk turmeric drying in PSD was simulated with four different mathematical models, namely,

Page model	$MR = e^{-k(x)n}$
Modified Page Model	$MR = e^{(-kx)n}$
Handerson and Pabis	$MR = ae^{-kx}$
Wang and Singh	$MR = 1+at+bt^2$

Sigma Plot version 14 was used to calculate non-linear regression for analyzing the curve-fitting data. The model equations were evaluated in coefficients of determination (R^2) and standard error of estimate (SEE).

RESULTS AND DISCUSSION

Performance evaluation of the Poly–house solar dryer and its system standardization was carried out under no-load and full-load tests taking different environmental conditions. Under no load test against solar radiation ranging from 478 to 530 W/m^2, drying air temperature reached the highest curves between 11:00 A.M. to 2:00 P.M., whereas the relative humidity of the system reached the lower curves during this same time as shown in Fig 3. Variation of temperature and humidity in cloudy day under no load test is shown in Fig 4.

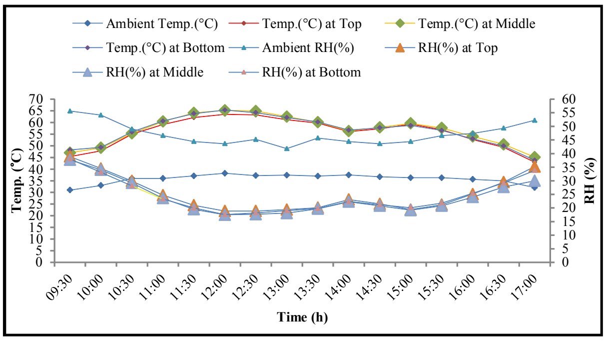


Fig. 3. Variation of temperature and relative humidity inside the dryer on a typical sunny day.

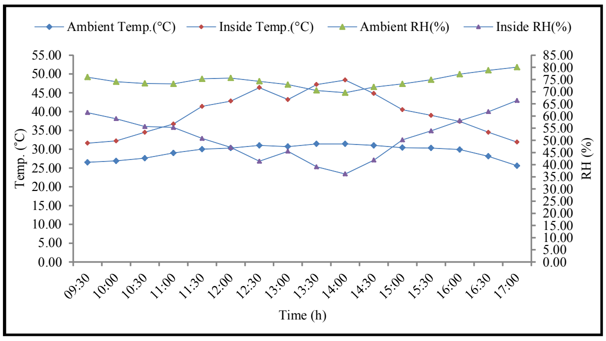


Fig. 4. Variation of temperature and relative humidity during day hours for a typical cloudy day.

During off sunshine or night, dryer temperatures gradually fall but relative humidity increases as shown in Fig 5. The ambient temperature and system drying temperature at different levels of solar radiation changed continuously from morning till evening. However, the relative humidity of the ambient system also changed due to the variation in solar radiation (Agbossou *et al.*, 2016).

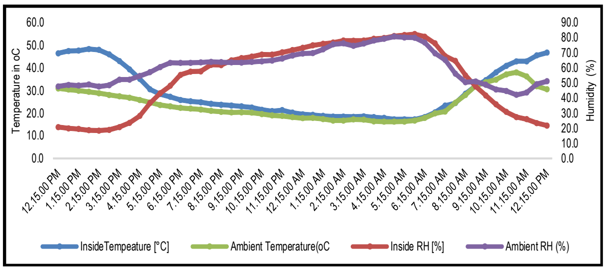


Fig. 5. Temperature and humidity under no load during off sunshine hours.

To tackle night-hour humidity all air inlets were covered with passive dehydrator – a sponge embedded with silica gel (held by a net). Under no load condition, there was 15-18% reduction of inside dryer humidity as shown

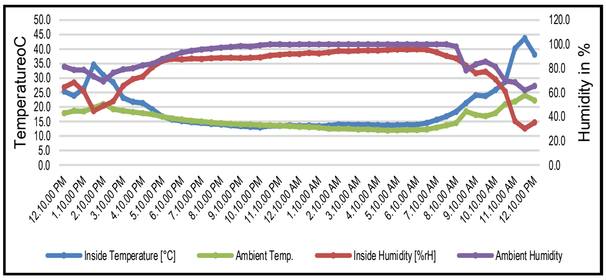


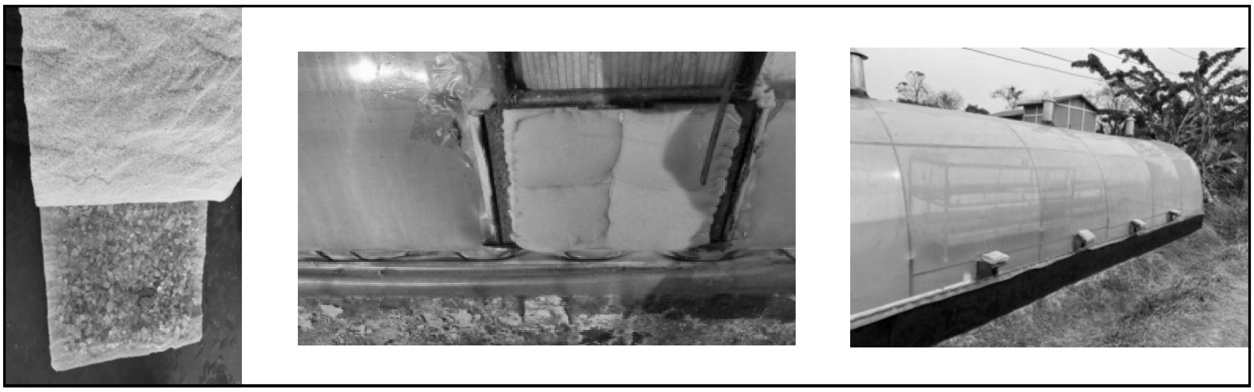
Fig. 6. Temp. and humidity under no load with a passive dehydrator at inlets.

in Fig 6. Passive dehydrators were kept in the open sun during the following day so that same can be re-used as shown in Fig 7.

The experiments of freshly harvested turmeric drying were carried out both inside PSD and under open sun drying (OSD) during February, 2021. The dryer was loaded with 650 kg blanched fresh turmeric at 11.20 A.M. on 18th February. Solar radiation data in watt per/m^2 during active drying duration, relative humidity in dryer compared to that of ambient and temperature in dryer compared to that of ambient are shown in Fig. 8(a), (b) and (c), respectively.

Thermal efficiency of PSD was calculated with the help of Eq 6 and found to be 28.89% at an average solar radiation of 521.46 watt/m^2. Intermittent variation of solar radiation by cloud cover on 2nd and 3rd day of drying was buffered by the heat storage component of the PSD and consequently, not much variation of temperature and relative humidity was seen inside the dryer as shown in Fig 8 (a), 8 (b) and 8 (c).

Fast drying at higher temperatures and low relative humidity during the diurnal part of the 24-h daily cycle inside PSD (Fig. 9) also prevented fungus growth. The quality of the dried produce from PSD was superior to OSD. Moisture removal from drying turmeric under OSD and PSD is shown in Fig 10.



(a) **(b)** **(c)**

Fig. 7. (a) Silica gel embedded in the sponge, (b) Embedded sponge fitted in air inlets and (c) Drying of embedded sponge during day time.

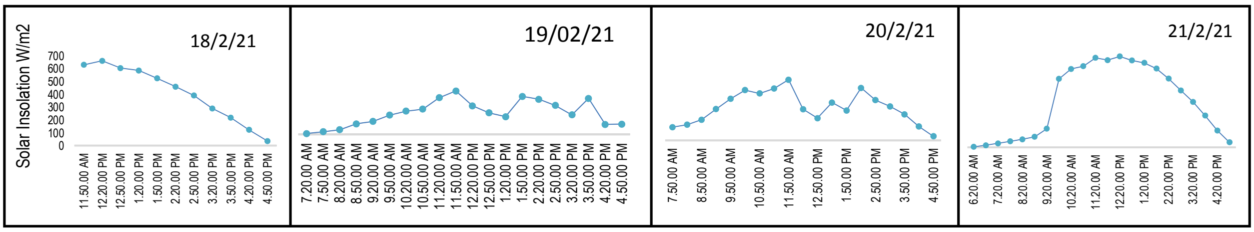


Fig. 8(a). Solar radiation during drying experiment.

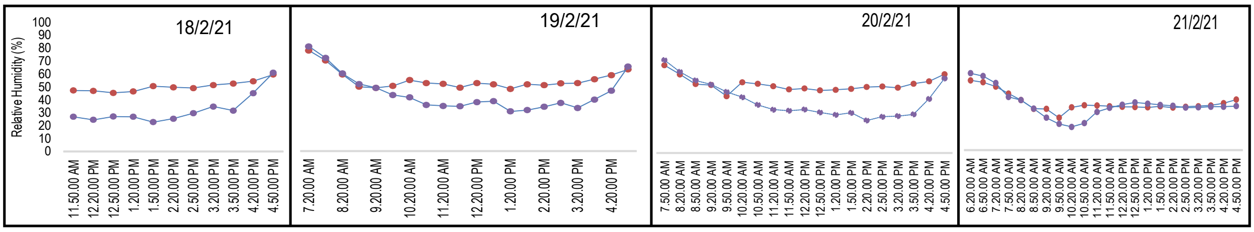


Fig. 8(b). Variation of average relative humidity in the dryer to that of ambient relative humidity.

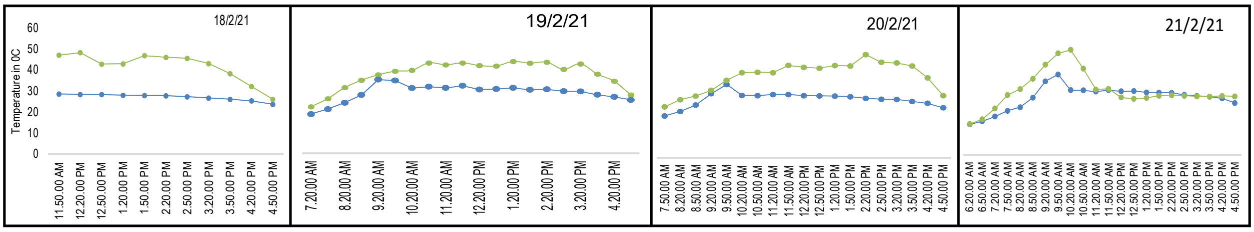


Fig. 8(c). Variation of average drying temperature inside the dryer to that of the ambient temperature.

Fig. 9. Turmeric drying view inside the dryer.

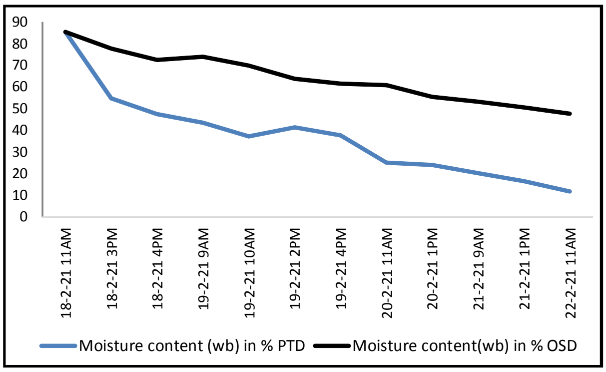


Fig. 10. Comparison of the moisture contents of turmeric inside PSD and OSD.

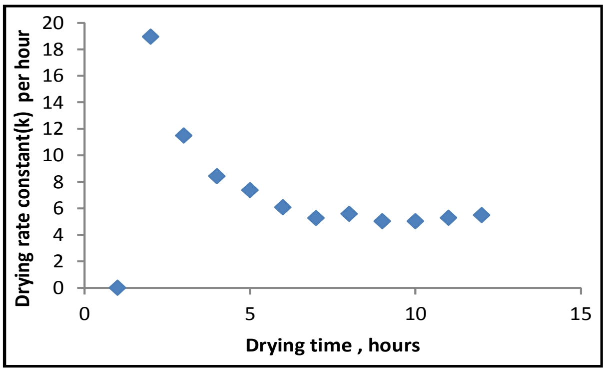


Fig. 11. Drying rate constant (k) against time.

Now, at solar insolation of 710 w/m^2, temperature inside the dryer is in the range of 55 - 60^{0}C and relative humidity is in the range of 20 to 25% with air flow velocity of 0.4 to 0.5 m/sec. Ambient relative humidity is 55-66%. The behaviour of drying turmeric slices was recorded for both OSD and PSD. The faster rate of moisture removal in PSD as compared to OSD was observed. In PSD sliced turmeric was dried from an initial moisture content of 585.87% (db) to a moisture content of 13.43% (db) in 22 h. In the same duration under open sun-drying moisture content of sliced turmeric could be brought down to 91.13% (db). While plotting the drying rate constant (k) against drying time it was observed that the drying rate under PSD was much faster in the initial hours of drying, however, it became extremely low after 11 h of drying (Fig. 11).

Table 3. Dimensions and design components of the solar tunnel dryer

Components	Specifications
Length of solar tunnel dryer	10.6 m
Diameter of solar tunnel dryer	4 m
The floor area of solar tunnel dryer	40.54 m^2
The area within the drying chamber	34.98 m^2
Height of the dryer at the centre	2 m
Height of northern insulated wall	0.6 m
Number of chimneys	3
Diameter of chimney	0.20 m
Height of chimney	0.75 m
Number of windows	4
Size of window	0.2 × 0.2 m
Total tray area (each rack)	2 × 3 m
Number of racks	3
Door size	1.6 × 0.5 m
Exhaust fan capacity	58 Watt

Table 4. Estimated value of the parameters of different tested drying models

Models	Equation	k	N	a	b	R^2	SEE
Page	$MR = e^{-k(x)n}$	1.275	0.336			0.9946	0.0200
Modified page	$MR = e^{(-kx)n}$	0.9618	0.7226			0.9475	0.0656
Hendorson and Pabis	$MR = ae^{-kx}$	0.6893		0.9910		0.9478	0.0656
Wang and Singh	MR = 1+at+bt^2			-01532	0.0053	0.3532	0.2308

Effective moisture diffusivity of turmeric drying in PSD was obtained from Eq. 8 by calculating the slopes derived from the linear regression of ln (MR) = ln A - kt versus time data (Fig. 12). PSD was tested against thin layer drying mathematical models with the help of moisture ratio (MR) calculated by Eq. 7 in simulating the drying behaviour of thin-layer drying of turmeric. Moisture ratio against drying time is shown in Fig. 13.

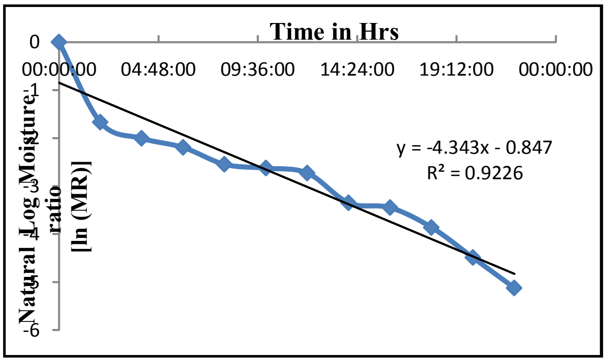


Fig. 12. LN (MR) against drying time for drying experiment with sliced turmeric.

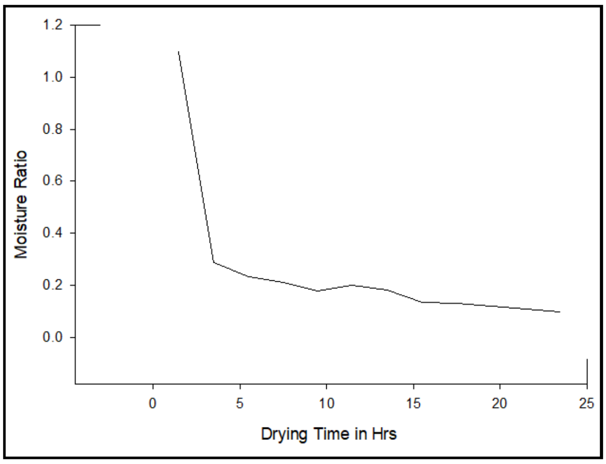


Fig. 13. Moisture ratio against drying time.

Among all the tested thin layer models, R^2 values as shown in Table 3 were greater than 0.9 in three models. Page model resulted in comparatively higher values of R^2 (0.9946) and lower values of SEE (0.0200). Therefore, Page model may be assumed to represent the thin layer drying behaviour of sliced turmeric in PSD.

CONCLUSION

Average solar radiation of the project site is 350 to 600 watt/m². The improved hemi-cylindrical dryer (span 10.2 m and radius 2 m of capacity 1000 kg) was found efficient for drying turmeric. Effective drying was accomplished only in the day hours. The developed dryer could generate hot air ranging from 42.70 to 54.32°C at an ambient temperature of 28.50 to 34.60°C. In the developed PSD, sliced blanched turmeric was dried from 85.42 to 11.2% (wb) in 22 h. Inside the dryer, minimal variation of 1-2°C of temperature was observed as such racks were used for drying. Time required for turmeric drying in PSD was considerably less in comparison to that of conventional open sun-drying. The system automation of forced convection was by moisture sensors during active drying period (day and night) and specifically improved drying efficiency and restricted the droplet formation during night. Among the drying models tested, Page model was found to represent the thin layer drying behaviour of sliced turmeric in PSD with R^2 value of 0.9946. There was 15-18% reduction of relative humidity inside the dryer by using silica gel embedded passive dehydrator. At average solar radiation of 521.46 watt/m², thermal efficiency was 24.89%.

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