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Performance and evaluation of foldable pyramid shape solar dryer for curry leaves (*Murraya koenigii*)

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Abstract
Curry leaves (*Murraya koenigii*) has great medicinal value and characteristic of curry leaves are flavour and aroma and because of this it is used in food preparation. The dried curry leaves more value and uses. The solar energy is freely available and pollution free. To protect the minerals and characteristics of curry leaves solar drying was most cost-effective alternative for drying. The pyramid shape solar dryer was used to dry the curry leaves. The performance of dryer was evaluated by conducting no load and load test for 26 days. For comparison sample is dried under the open sun drying. The moisture content, moisture ratio, drying ratio, bulk, true, and porosity was determined. The moisture content of sample was reduced from 69.9% to 6.4% in 7 hrs.

Keywords: Pyramid shape, solar dryer, drying

Introduction
Grain and pulse crops and agricultural processed products that can withstand storage conditions should be dried to their equilibrium moisture content. For the safest storage of a hardy crop, the ideal warehouse temperature range is between 25 and 30 °C, with a relative humidity of between 65% and 75%. Consequently, it is possible to say that drying is the process used to remove extra moisture from grain and lower moisture levels to a level that is appropriate for safe storage. Drying reduces losses during storage due to things like premature and out-of-season germination of the grain, mould development, and insect growth.

"Sun drying" has been a popular traditional method to preserve cultivated crops since prehistoric times. Among the several methods currently in use, open-air sun drying is popular because it is inexpensive, but it has the significant problem of losing a lot of thermal energy, which leads to inefficient use of heat during the process and is not uniform and controllable. As a result, the drying process is hampered, which lowers the output rate and quality also lengthens the drying time. In addition to decreased thermal efficiency, other elements like the weather, rain, wind, birds, bugs, and rodents have an impact. Additionally, the growth of fungus in dried food crops due to slow and uncontrolled external parameters increases the risk of food contamination and diseases associated with food in this regard, developed modern and improved drying systems can solve the afore mentioned issues with drying systems

Studied area
The development and study of laboratory performance of folding type pyramid shape solar dryer was carried out at Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli. The developed dryer was laboratory tested at Energy Park, Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dapoli.

Methodology
Selection of drying product
The criteria for selection of drying material was cheap, abundantly available in region having commercial value and demand easily available with lot of medicinal properties and regularly used in Indian cousin. The dried curry leaves (*Murraya koenigii*) are commercially used by making it to powdered form.

Table 1: Design considerations for folding type pyramid shape solar dryer

Sr. No.	Particulars	Considerations
1	Type of drying material	Curry leaves (*Murraya koenigii*)
2	Mode of drying	Natural convection
2	Initial moisture content, mi	69.9% (wb)
3	Final moisture content, mf	6.4% (wb)
4	Weight of the material	5 Kg.
5	Location	Dapoli
6	Latitude/Longitude	17˚45'N 73˚26'E
7	Ambient humidity	65%
8	Ambient air temperature	27 °C
8	Avg. sunshine hours (drying period)	8 hrs.
9	Max drying temperature	55 °C
10	Latent heat of vaporisation of water	540 kcal/kg.
11	Specific heat of water	1 kcal/kg. ˚k
12	Absorptivity, transmissivity constant (τ. α)	0.3
13	Solar insolation	400 w/m^2
14	Wind speed	2 m/sec

Design calculations

Mass of water to be evaporated from product

Amount of moisture to be removed from a given quantity of curry leaves to bring the moisture content to a safe storage level in a specified time. The amount of moisture to be removed from the product, "mw", in kg was calculated using the following equation

$$mw = \frac{mp(mi-mf)}{(100-mf)} \quad (1)$$

Where
mw= Amount of moisture to be removed from product, (kg)
mp= Initial mass of product to be dried, (kg)
mi= Initial moisture content wb, (%) (Oven dry method
mf= Final moisture content wb, (%)

Quantity of heat needed for drying

The quantity of heat required to evaporate the water is:

$$Q = Wdr \times Cp \times (Tc-Ta) + Wdr \times hfg \quad (2)$$

Where
Q = the amount of energy required for the drying process, KJ
Wdr = mass of water, kg
Cp = specific heat of water 1 Kcal/Kg
Tc = maximum drying temperature °C
Ta = Avg. Ambient temperature °C
hfg = latent heat of evaporation, 540 kcal/kg water (at STP)

Area of collector

Area of collector is given by following equation:

$$A = \frac{Q}{(I \times (\tau.\alpha) \times Td)} \quad (3)$$

Where
A = Area of collector (m^2)
Q = Total Heat required for drying (KJ)
I = Avg. intensity of solar radiation (KJ/m^2.sec)
Td = Total drying Time (sec)
τ.α = Transmissivity and absorptivity constant

Area required for drying

Area required for drying is a ratio of weight of product to be dried to the drying density of the product

$$a = W/\rho d \quad (4)$$

Where
a = Area required for drying, (m^2)
w = weight of the product, (kg)
ρd = Drying density (kg/m^2)

Calculation of drying density

Drying density of curry leaves was calculated by finding weight of curry leaves sample occupying 1 square meter areas shown in plate 1 (ρd=Drying density kg/m^2= 2.02 kg/m^2)

Dryer dimensions

The dimensions of the dryer were calculated by the expression 5.

$$Area = D \times L \quad (5)$$

Where
Area = collector area A_c, m^2
D = width of dryer, m
L = length of the dryer, m

Computation of pyramid dimensions

h = height =0.91 m
s = slant height=1.18 m
a = side length=1.50 m
e = lateral edge length=1.40 m
L = lateral surface area=3.5 m^2
B = base surface area=2.25 m^2
A = total surface area=5.79 m^2

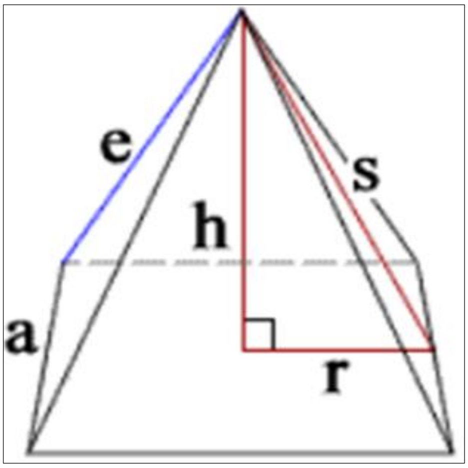

Fig 1: Notations of the pyramid dimensions

Number of trays

Number of trays were calculated by the relationship between actual drying area from the density of curry leaves and total collector area.

$$\text{Number of trays} = \frac{\text{actual drying area}}{\text{Total collector area}} \quad (6)$$

Area of drying trays

Table 2: Specifications of drying trays

Sr. No.	Tray	Dimensions (cm)	Area of tray (cm^2)	Distance from top (cm)
1	Tray 1	28×33	924	28
2	Tray 2	56×60	3360	56
3	Tray 3	84×87	7350	84
4	Tray 4	112×116	12992	112
		Total area	24626	

Dimensions of chimney

The airflow rate in the dryer took place due to draft caused by the pressure difference between outside cold air and inside hot air.

$$P = 0.000308\ g\ (T_i - T_f)\ H \quad (7)$$

Where

P = pressure difference between outside cold air and inside hot air, Pa.

g = acceleration due to gravity 9.81 m/s^2

H = height of the chimney, m.

Actual draft was assumed to be 75% of this draft (P)

Actual draft (PI) = 0.75 x P

$$\text{Velocity of exit air (c)} = \sqrt{\frac{2\ X\ PI}{\rho_e}} \quad (8)$$

Volume of exit air (v_e) = quantity of air in kg / ρ_e

Rate of exit air (q_e) = v_e / drying time

Cross sectional area of chimney (a_c) = $\frac{q_e}{c}$

Hence diameter of chimney (d) = $(4 \text{ x ac} / \pi)^{0.5}$

Upper diameter (dI) of chimney was 75% of the lower one (d).

So, with the above equation diameters d and dI and height H of chimney was determined.

Table 3: Design parameters pyramids shape solar dryer

Sr. No.	Parameters	Value
1.	Mass of water to be evaporated	3.38 kg
2.	Length of dryer	1.5 m
3.	Width of dryer	1.5 m
4.	Number of trays	4
5.	Area of air vent	0.0087 m^2
6.	Pressure difference between outside cold air and inside hot air (P)	0.00957 Pa
7.	Solar collector area	1.8 m^3
8.	Actual draft (PI)	0.00713 Pa
9.	Velocity of exit air (c)	0.36 m/s
10.	Volume of exit air (v_e)	421m^3
11.	Rate of exit air q_e	66.19 m^3 / hr

Plate 1: Pyramid shape foldable solar dryer

Following tests was carried out for performance evaluation of the folding type pyramid shape solar dryer:

A. Laboratory tests (summer)

1. No Load Test
2. Full Load Test

The following parameters were measured during the no load testing of the folding type pyramid shape solar dryer with respect to time (1 hr. interval):

1. Solar Intensity (W/m^2)
2. Ambient air temperature (°C)
3. Ambient Relative Humidity (%)
4. Temperature at tray 1 (T1) (°C)
5. Temperature at tray 2 (T2) (˚C)
6. Temperature at tray 3 (T3) (°C)
7. Temperature at tray 4 (T4) (°C)
8. Inside Relative Humidity (Dryer) (%)

Full load testing of folding type pyramid shape solar dryer

For full load test fresh green curry leaves (*Murraya koenigii*) are taken. The initial weight of the samples was recorded. The samples were weighed regularly at an interval of 1 hour from all the trays and simultaneously the temperature, relative humidity, inside the folding type pyramid shape solar dryer was measured with solar intensity. Drying was conducted between 9.00 to 17.00 h.

The samples were kept for drying in open sun for comparing the performance of the folding type pyramid shape solar dryer with respect to open sun drying. This samples also weighed regularly at an interval of 1 hour and simultaneously the temperature, relative humidity is measured. Drying was conducted between 9.00 to 17.00 h. as shown in Plate 1.

Following parameters were measured during load testing of the folding type pyramid shape solar dryer with respect to time. (1 hr. interval)

1. Solar Intensity (W/m^2)
2. Ambient air temperature (°C)
3. Ambient Relative Humidity (%)
4. Temperature at tray 1 (T1) (°C)
5. Temperature at tray 2 (T2) (°C)
6. Temperature at tray 3 (T3) (°C)
7. Temperature at tray 4 (T4) (°C)
8. Inside Relative Humidity (Dryer) (%)

9. Average weight reduction of selected samples in solar dryer (gm.)
10. Average weight reduction of selected samples in open sun drying (gm.)

Results and Discussion

No load testing of pyramid shape Foldable solar dryer

The dryer was tested without loading and different atmospheric parameters were measured like temperature, relative humidity, solar intensity, at every one-hour interval was recorded. The no load test was conducted for thirteen days the solar intensity gradually increased from 9000 hrs and it went on increasing till it attained its peak at 1300 hrs. However, all the temperatures at Tray 1, Tray 2, Tray 3, Tray 4 along with ambient temperature T(out) followed a similar trend and it clearly showed a direct relation with the solar intensity because the temperature of all the trays studied for 13 days increased with respect to the solar intensity and the maximum temperature was attained at 1300 hrs. The values of solar intensity and temperatures found out during the study carried out at Energy Park, DBSKKV, Dapoli were in correspondence with the values found during various studies previously carried out at the same place (Avinash *et al.* 2016).

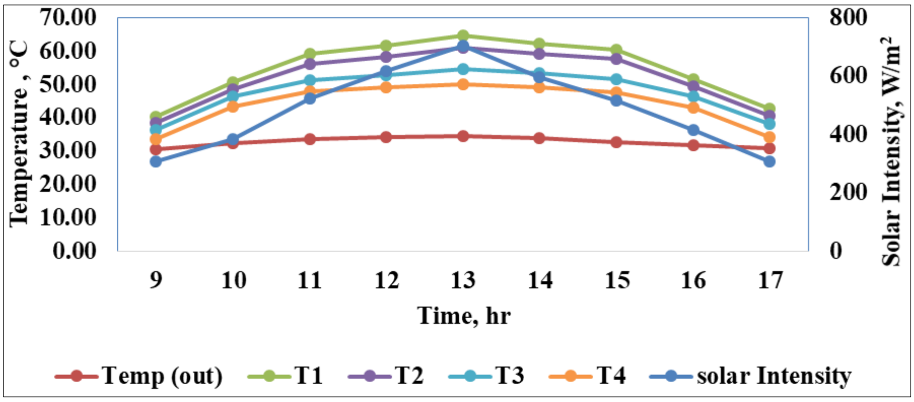

Fig 2: Average temperature variation during no load test

The above graph revealed that the solar intensity was increasing from 9000 hrs to 1300 hrs and decreasing from 1300 hrs to 1700 hrs. The peak value of temperature 64.42 °C for tray 1, 60.82 °C for tray 2, 54.42 °C for tray 3 and 50.11 °C for tray 4 and 34.48 °C ambient temperature peak value corresponding with solar intensity of 704 W/m^2 obtained at 1300 hrs.

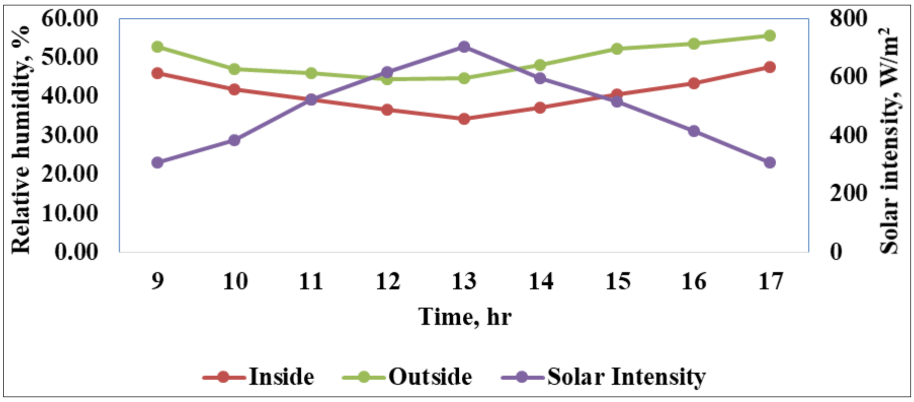

Fig 3: Average relative humidity variation during no load test

The above graph revealed that the maximum relative humidity 46% and 47, 60% with ambient relative humidity value 52.67% and 55.60% was obtained at 9000 hrs and 1700 hrs respectively due to minimum temperature. The least value of relative humidity inside the dryer was 34.27% and ambient relative humidity least value 44.60% at 1300 hrs with solar intensity of 704 W/m^2. (Avinash *et al.* 2016).

Full Load testing of Pyramid shape foldable solar dryer

The samples of curry leaves (*Murraya koenigii*) were loaded in thin layer drying on all four trays inside the folding type pyramid shape solar dryer on its full loading capacity of 5 kg. The full load testing was carried out for 13 days. The drying of curry leaves was continued till the moisture content reached about 6.4 percent on wet basis.

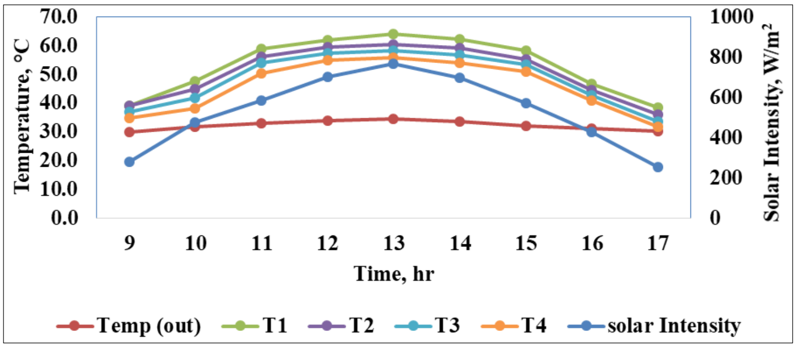

Fig 4: Average temperature variation during load test

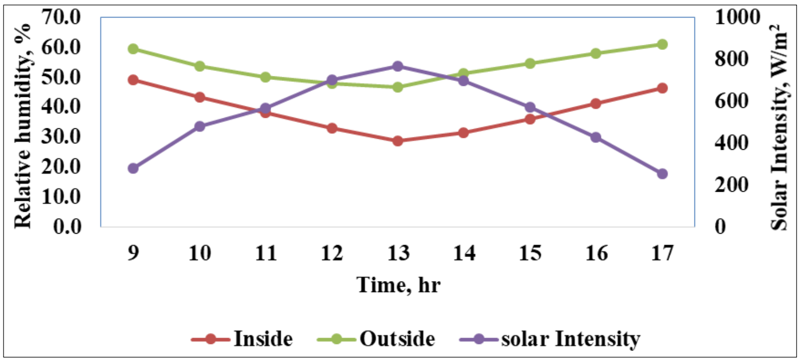

Fig 5: Average relative humidity variation during load test

The above graph revealed that the peak value of temperature for tray 1 was 63.1 °C and least value of temperature for tray 4 was 55.7 °C at 1300 hrs with solar intensity of 767 W/m^2 and ambient temperature value of 34.5 °C. the value of temperature for tray 2 and tray 3 were 60.5 °C and 58.3 °C respectively. It also shows that the value of temperature is increasing with increase in solar intensity.

The graph of relative humidity revealed that there is much difference in value of relative humidity of inside and outside the solar dryer. The least value of relative humidity recorded in solar dryer was 28.8% and ambient relative humidity value was 46.7% with solar intensity value of 767 W/m^2.

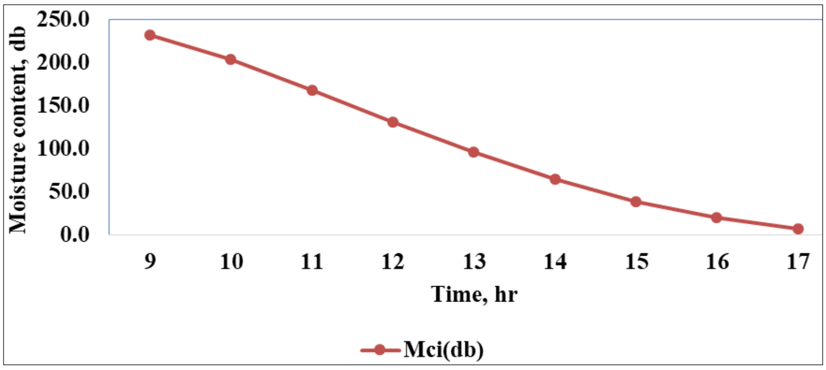

Fig 6: Variation of average moisture content of curry leaves in solar dryer

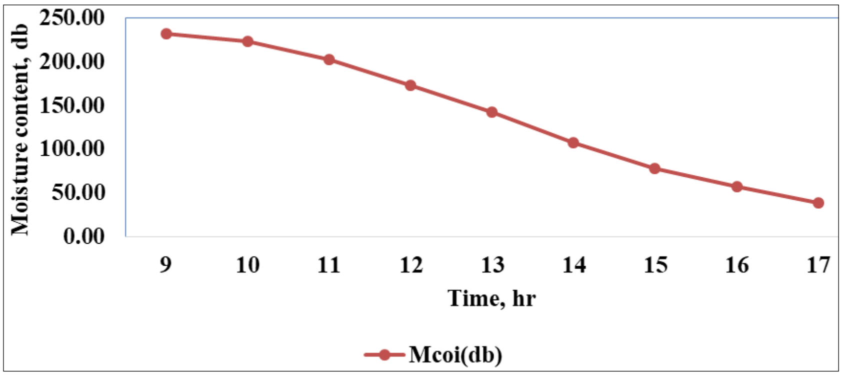

Fig 7: Variation of average Moisture content of curry leaves in open sun drying

Fig. 6 and fig. 7 represented the average moisture content (db) of curry leaves inside folding type pyramid shape solar dryer and open sun drying respectively. Fig 6 revealed that the moisture content of curry leaves samples in folding type pyramid shape solar dryer were reduced from 69.9 percent to 6.4 percent in 7 hrs in folding type pyramid shape solar dryer. And in open sun drying moisture content was reduced from 69.9 to 39.28 in a day. (Avinash *et al.* 2016).

Conclusions

1. The maximum average temperature inside the folding type pyramid shape solar dryer during no load tests was found to be 64.2 °C during trials with corresponding ambient temperature 34.48 °C with 767 W/m^2 value of solar intensity. The average relative humidity value during no load test was found to be 34.27% and corresponding value for ambient relative humidity was 44.60%.
2. The supreme temperature inside the folding type pyramid shape solar dryer during Full load tests found to be 63.9 °C and ambient temperature value was 34.5 °C with solar intensity value 767 W/m^2. The relative humidity was found to be 28.8% and ambient value was 46.7%.
3. Folding type pyramid shape solar dryer took 7 hrs. to bring down 69.9% of moisture content of curry leaves to the safe storage level of 6.4% of moisture content in diverse seasons, as related to 10 hrs. in open sun drying.

It can be concluded that from the above study, it is concluded that, the folding type pyramid shape solar dryer can be successfully used for domestic drying of curry leaves in less time compared to open sun drying.

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