



Design and development of hybrid solar dryer for flowers

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ABSTRACT

A hybrid solar dryer was developed consisting of three shelves of 0.55 m² area each in the drying chamber. This dryer works on the principal of solar thermal and solar photovoltaic system. The performance evaluation was done with rose and marigold flowers. It was found that both flowers when dried at 45°C were significantly ($P < 0.05$) better in terms of retention of anthocyanin and carotenoid content, shape, texture, brittleness, intactness, colour and per cent reduction in diameter. Moisture content (w.b) reduction from 90–14%, total drying time (h), reduction in diameter (%), overall drying rate (%/h) and anthocyanin content (mg/g) for solar dried sample was 31.66, 7.43, 2.32 and 2.49 respectively, whereas for control (sun dried) it was found to be 53.66, 17.85, 1.38 and 1.21 respectively. The time of drying was lesser by 65% and 70% for rose and marigold flowers when dried in solar dryer. The sensory analysis showed that solar dried samples were superior in terms of shape, colour, texture, brittleness and intactness as compared to control. Thus the overall acceptability of flowers dried using the developed dryer was better.

Key words: Flower drying, Solar dryer

Floriculture in India is being viewed as a high growth industry. Owing to steady increase in demand of flower, floriculture has become one of the important commercial trades in agriculture. Hence, commercial floriculture has emerged as hi-tech activity-taking place under controlled and open field climatic conditions. About 309.00 thousand ha area was under cultivation in floriculture during 2016–17 in India (Anonymous 2017).

Dried flowers and plants have been exported for the last 40 years and today India is one of the leading countries in the field. Various products of dried flowers are handmade paper, lampshades, wall quilt, decorations, books, candle holders, greeting cards, wall hangings, flower arrangements using dried sample of cone, foliage, flower like rose buds, lilies and other such plant material are adding more export value to floral industry (Aruna *et al.* 2011). For drying of flowers and foliage, number of dehydration techniques are practiced which vary according to the suitability of any species and the purpose for which dehydrated material is required. These methods are air drying, sun drying, solar drying, hot air oven drying, microwave drying, freeze drying and vacuum drying, embedding drying, press drying, etc.

(Namita *et al.* and Pinder and Namita 2018).

The Sun is the biggest fusion reactor known to mankind which supply energy to earth daily about 1000 times more than we need. This energy is received for over 250–300 clear sunny days per annum; in certain areas the bright sunny days may be more (Yadav 2015). Two main approaches currently in use to harness solar energy are converting solar energy to electricity by the photovoltaic approach and converting solar energy to thermal energy by the solar thermal conversion. The simplest and most efficient way to utilize solar energy is to convert it into thermal energy for heating applications. The economic feasibility of solar energy utilization depends upon its efficient collection, conservation and storage (Garba 1991). Thus in a world that is struggling to fight against global warming and other environmental deteriorating factors due to use of conventional fuels for energy, use of unconventional methods like solar drying can prove to be beneficial for all. In view of the above, a hybrid solar dryer was designed and developed for drying of flowers.

MATERIALS AND METHODS

The study was carried out at ICAR-Indian Agricultural Research Institute, Pusa, New Delhi, during 2018. The flowers of rose (*Rosa × hybrida*) and marigold (*Tagetes erecta*) were selected for the present study. Rose is a woody perennial flowering plant of family Rosaceae and is one of the most important commercial crops grown for cut and loose flower production (Vasudevan and Kannan 2015).

Marigold belongs to family Asteraceae and grown for loose flower production in India. The fresh flowers were procured regularly before each performance evaluation from

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The detailed design procedure and related calculations are stated in the following sections;

Angle of Tilt (β) of solar collector: New Delhi lies along the latitude 28.70°N . Hence the suitable value of β used for the collector was: $\beta = 10^\circ + 28.7^\circ = 38.7^\circ$.

Insolation on the collector surface area: The value of insolation for New Delhi, i.e. average global horizontal irradiance H on horizontal surface is 5.2 kWh/m^2 and considering 7.35 h of average annual bright sunshine h (Anonymous 2017), $H = 706.89 \text{ W/m}^2$. So the average effective ratio of solar energy on tilted surface to that on the horizontal surface R becomes

$$R = 1.0035 \times 706.89 = 709.36 \text{ W/m}^2$$

The mass flow rate of air was determined by taking the average air velocity $V_a = 0.18 \text{ m/s}$. The air gap height was taken as $6 \text{ cm} = 0.06 \text{ m}$ and the width of the collector was assumed to be $3 \text{ ft} = 0.91 \text{ m}$.

Therefore, volumetric air flow rate comes out to be;

$$V_a = 0.18 \times 0.06 \times 0.91 = 0.010 \text{ m}^3/\text{s}$$

The density of air is 1.28 kg/m^3 . Hence mass flow rate of air;

$$M_a = 0.010 \times 1.28 = 0.0129 \text{ kg/s}$$

Specific heat of air = 1020 J/kg K , Difference between ambient temperature and drying temperature = 30°C , Assumed thermal efficiency in fraction = 0.5 .

The area of collector is determined as;

$$A_c = \frac{0.0129 \times 1020 \times 30}{0.5 \times 709.36} = 1.11 \text{ m}^2$$

Hence the length of the collector becomes;

$$L = \frac{1.11}{0.91} = 1.22 \text{ m}$$

So a dryer with collector dimensions $1.22 \times 0.91 \text{ m}$ was constructed having collector area equal to 1.11 m^2 .

The total heat required for drying of flowers depends upon the type of flower, its moisture content, the embedding material and the material of tray used for embedding. As flowers of rose have higher densities (bulk and true) and moisture content, the heat requirement of roses will be higher than that of marigold. So we determined the heat required for drying roses only. The selected drying temperatures were 45°C , 50°C and 55°C .

$$Q = Q_f + Q_s + Q_t$$

where, Q , Total heat required for drying (kJ); Q_f , Heat required by flowers (kJ); Q_s , Heat required by silica (kJ); Q_t , Heat required by the tray (kJ).

Heat required by flowers includes both sensible heat of raising the temperature and latent heat of evaporation of water. As maximum loading capacity is 9 trays with 9 flowers in each and each tray requires 2 kg of silica gel to completely embedding the flowers

$$\text{Mass of flowers} = 9 \times 9 \times 11.65 = 943.65 \text{ g or } 0.94 \text{ kg}$$

$$\text{Mass of water in flowers with } 90\% \text{ initial moisture content (w.b)} = 9.94 \times 0.9 = 0.85 \text{ kg}$$

We assume specific heat of rose equal to that of lettuce as both contain 90% (w.b.) moisture content = 4.02 kJ/kg K (Anonymous 2018)

Latent heat of evaporation of water = 2260 kJ/kg ,

$$Q_f = (0.94 \times 4.02 \times 30) + (0.85 \times 2260) = 2034.36 \text{ kJ}$$

Similarly, Specific heat of silica = 1.13 kJ/kg K (Anonymous 2018)

$$Q_s = 18 \times 1.13 \times 30 = 610.2 \text{ kJ}$$

Specific heat of PVC tray = 1.17 kJ/kg K (Anonymous 2018)

$$Q = 0.2 \times 1.17 \times 30 = 7.02 \text{ kJ} = 2034.36 + 610.2 + 7.02 = 2651.58 \text{ kJ}$$

So a total of 2651.58 kJ of heat will be required for drying of flowers. Three resistance heating coil of 12V and 100 W each were used for auxiliary heating unit. 12V solar panel was used to operate the auxiliary heating unit, fans and the automation system. A 150 ampere-hour battery was charged during the day by solar energy to use during night for operation of the system.

The dryer was automated so that the temperature inside the drying chamber can be maintained to a desired constant value. Three DHT 22 temperature and relative humidity sensors were employed to measure and record temperature and relative humidity of ambient air, air from the outlet of solar collector and the exhaust air. A temperature sensor (Dallas 18 B 20 make) was used to measure and record the temperature inside the drying chamber. The automation was done using microcontroller board (Arduino Mega 2560) based on microcontroller chip (ATmega 2560).

Granite rocks of oval shape (540 kg) having mean longest dimension of 9.8 cm were used as packed bed thermal storage. These were painted black to absorb the maximum possible solar radiation to store more heat. This storage unit utilizes the heat capacity of the rocks to maintain the temperature during night when there is no sun (Tiware and Suneja 1997).

The performance of solar collector is affected by glaze, transmittance, absorptance and reflectance which results into major heat losses in the system (Bakari *et al.* 2014). Locally available plastic trays of dimensions $0.29 \text{ m} \times 0.23 \text{ m} \times 0.06 \text{ m}$ were used for embedding flowers. The depth of the trays ensured that the flowers were properly embedded with 2.5 cm of silica layer at the top as well as at the bottom of the flowers. The tray also provided enough area to embed flowers without touching each other. Three 12V DC fans were used to pull the heated air from the solar collector into the drying chamber to facilitate the movement of moisture laden air out of the drying chamber. The rotational speed of blades was 3500 rpm and displaced 5.53 CFM of air in working condition.

The hybrid solar dryer was tested for no load conditions to determine the maximum temperature difference attained and the temperature profile of the dryer. Testing under load conditions was done to evaluate the performance of the mixed-mode solar dryer in actually loaded conditions.

Marigold and rose flowers were dried during these tests. Separate tests were performed for the flowers and 36 numbers of flowers were dried in each test. The flowers were embedded in silica gel so as to maintain their properties like shape, size and texture. Embedding of flowers was done according to method used by Rani and Reddy (2015).

Analysis of anthocyanin and carotenoid content: The anthocyanin and carotenoid content was determined for rose flowers before and after drying in each treatment. Quantification of total anthocyanin was done according to the method described by Ram *et al.* (2011). The total carotenoids were extracted by method given by Ranganna (1995).

Sensory analysis: The method of sensory analysis was used to evaluate the quality of dried flowers. It is a method which employs human senses (sight, smell, touch, taste and hearing) for the purpose of evaluation. Different parameters like shape, colour, texture, intactness and brittleness were evaluated by a panel of five members. Each treatment was evaluated by the panel after drying and the respective scores were recorded. The scale used for scoring was similar to that followed by Ugale *et al.* (2016).

Change in colour: The Royal Horticulture Society Colour Chart is the standard reference used by horticulturists worldwide for recording plant colours. The flower colour before and after drying was recorded using RHS Colour Chart fifth edition.

Collector efficiency: Collector efficiency is the measure of collector performance and is defined as the ratio of useful gain over a time period to the incident solar energy over same time period (Rai 1995).

Total drying time: The total drying time for each treatment replication was recorded during the performance of experiment in h. The time taken for drying flowers during each replication was averaged to get the time required for drying for the respective treatment.

Overall drying rate: Drying rate is the ratio of per cent of

moisture removed per unit time. The overall drying rate was calculated as per method suggested by Raol *et al.* (2013).

No load testing: The no load testing was done for both conditions when the collector of solar dryer had single and double glass cover. Periodic variation of different temperatures at different points is shown in Fig 1. The ambient temperature increased till 13:43 PM and started falling after that. The maximum temperature difference that was 15.1°C for collector with single glass cover.

The temperature profile for the same points inside and outside the dryer for double glass cover has been shown in Fig 2. The ambient temperature increased until 14:30 PM and started decreasing after that. The maximum temperature difference between the ambient and temperature of collector outlet was found out to be 18°C. It is evident from the graph that the temperature profile for different points varied more with the ambient temperature conditions for single glass cover as compared to the double glass cover.

RESULTS AND DISCUSSION

Collector efficiency: The velocity of air through a single fan was recorded to be 1.25 m/s. The diameter of the blade was 0.076 m and the area comes out to be $4.53 \times 10^{-3} \text{ m}^2$. As there was three fans thus the mass flow rate of air $\dot{m}_a = 3 \times 4.53 \times 10^{-3} \times 1.23 = 6.9 \times 10^{-3} \text{ kg/s}$.

Thus the collector efficiency for the single glass cover was found to be;

$$\eta_c = \frac{6.9 \times 10^{-3} \times 1020 \times (45-32.11)}{866.3 \times 1.11} \times 100 = 28.56\%$$

Similarly for double glass cover;

$$\eta_c = \frac{6.9 \times 10^{-3} \times 1020 \times (48.38-33.07)}{873.1 \times 1.11} \times 100 = 33.35\%$$

Thus we can see that the efficiency of solar collector increased from 28.56% for single glass cover to 33.35%

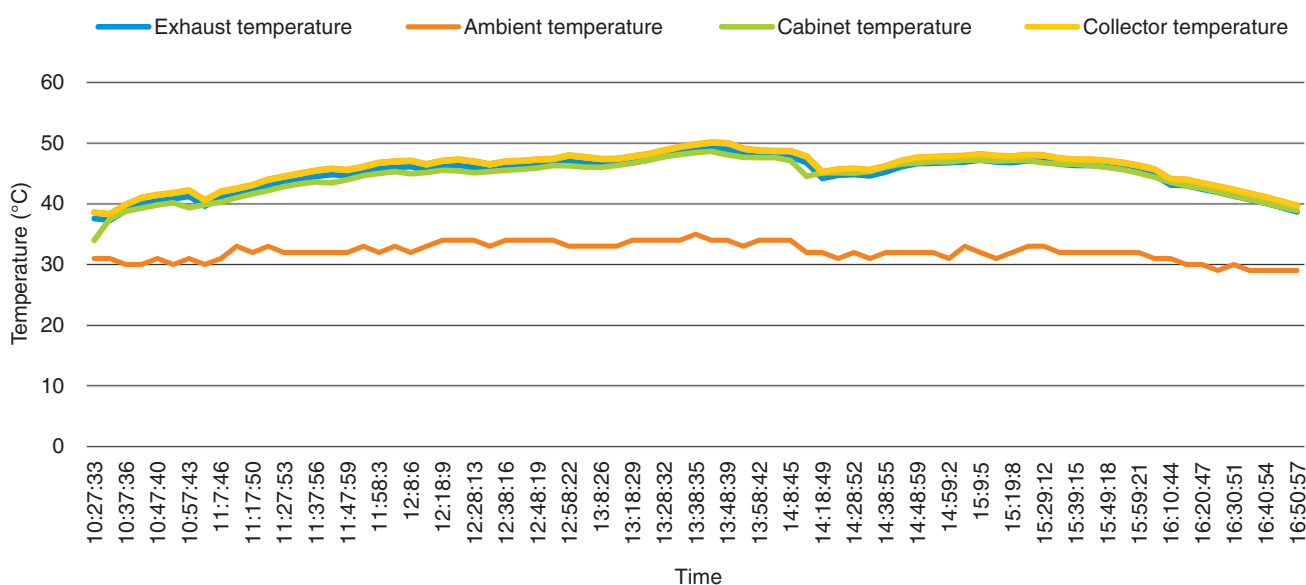


Fig 1 Time versus temperature graph for single glass cover.

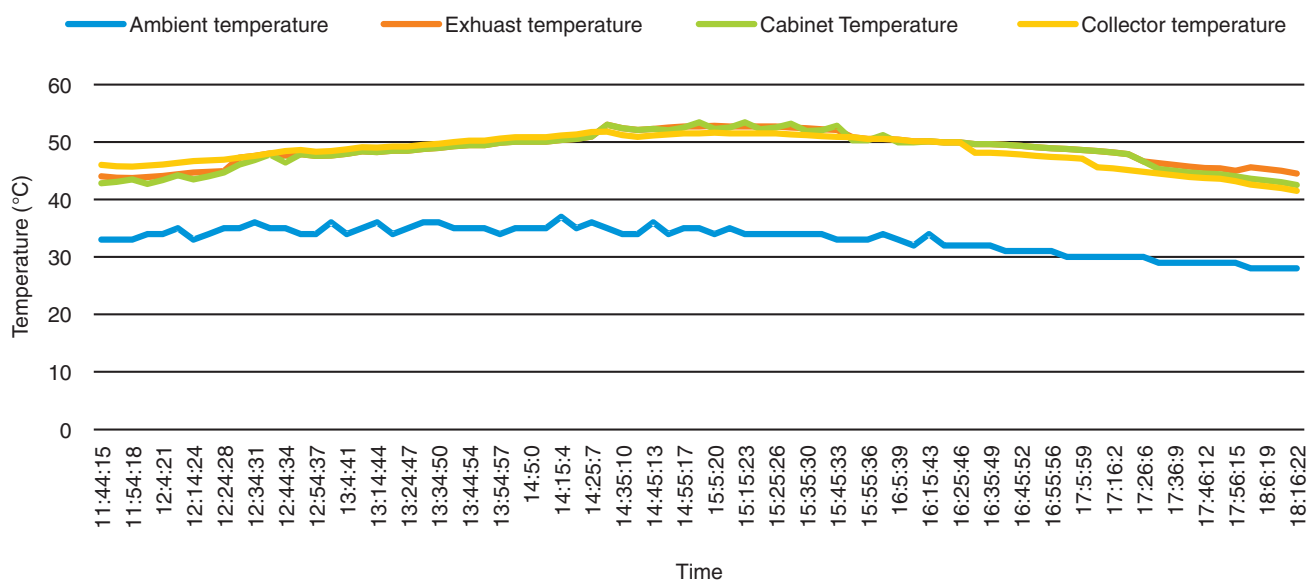


Fig 2 Time versus temperature graph for double glass cover.

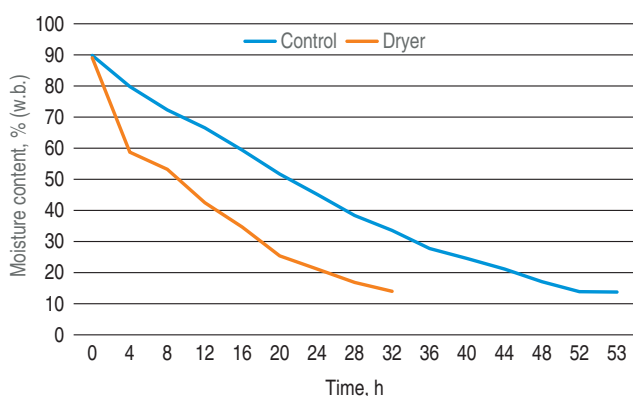


Fig 3 Hourly variation of Moisture content (%) for rose flowers in solar dryer and open sun.

Time

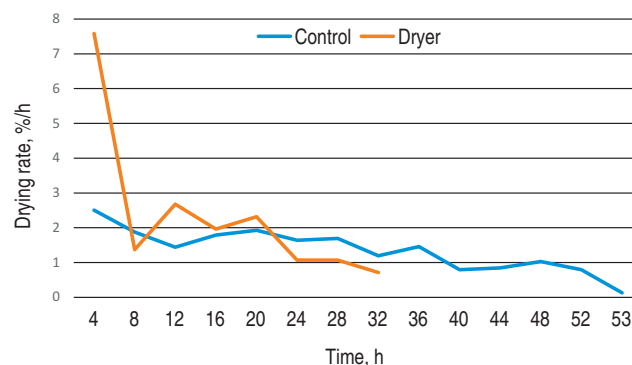


Fig 4 Hourly variation of drying rate (%/h) for rose flowers in solar dryer and open sun.

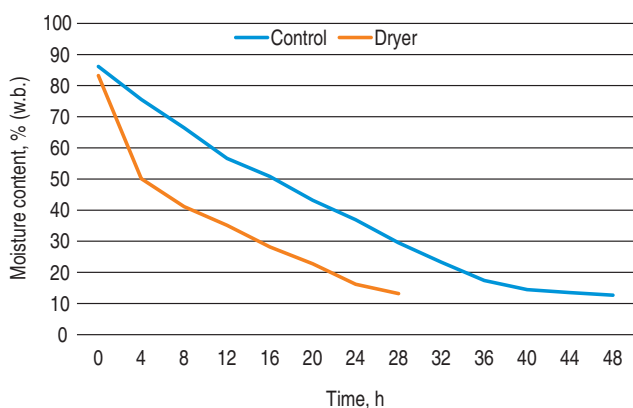


Fig 5 Hourly variation of Moisture content (%) for arigold flowers in solar dryer and open sun.

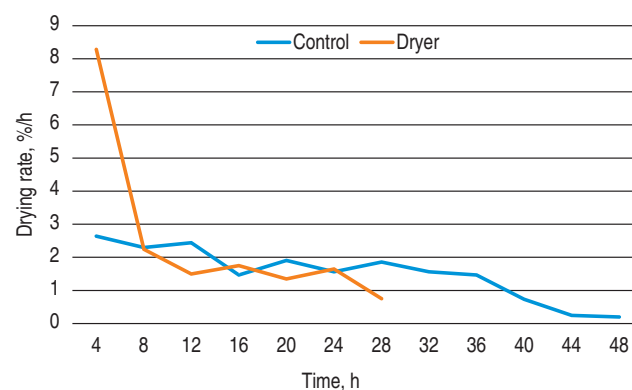


Fig 6 Hourly variation of drying rate (%/h) for marigold flowers in solar dryer and open sun.

by using double glass cover.

Comparison with control: For comparing the flowers dried in embed condition under sun and flowers dried at 45°C equipped with double glass cover; paired t-test was performed between the quality parameter of the samples. For rose flowers, it was found that all the parameters between

the two samples varied significantly. The standard error of difference for texture came out to be zero. In case of marigold flowers the parameters like shape and intactness had zero standard error of difference while all other parameters were significantly different.

It was found that the flowers dried using solar dryer

Table 1 Mean values of different parameters of rose and marigold flowers for open sun dried (control) and the sample dried in solar dryer

Parameter	Rose		Marigold	
	Open sun dried (Control)	Dried in solar dryer	Open sun dried (Control)	Dried in solar dryer
Total drying time (h)	53.66	31.66	48.33	28.66
Reduction in diameter (%)	17.85	7.43	35.66	11.45
Overall drying rate (%/h)	1.38	2.32	1.51	2.53
Anthocyanin (mg/g)/carotenoids(mg/100 g)	1.21	2.49	1025.55	3360.45
Shape	1.00	2.86	1.00	2.86
Colour	1.30	3.86	1.13	3.93
Intactness	83.33	100.00	80.00	100.00
Brittleness	3.93	1.06	4.00	1.86
Texture	1.06	3.86	1.06	3.13

exhibited better quality in terms of all the parameters considered than those dried in open sun (control) (Table 1). It can be seen that the time required for drying was reduced in solar dryer as compared to open sun drying for both the rose and marigold flowers by 65% and 70% respectively (Fig 3 and 4). The moisture removal rate was higher when flowers were dried in the dryer as compared to the sun dried samples, for both rose flowers and marigold flowers (Fig 5 and 6). The drying rate was also influenced by the intensity of the solar radiations.

Flowers dried in the hybrid solar dryer were found to be superior in terms of quality parameters like retention of anthocyanin/carotenoid content, shape, texture, brittleness, colour and intactness. The time of drying was lesser by 65% and 70% for rose and marigold flowers when dried in solar dryer. The effect of dust and loss of silica gel due to wind is also reduced by the use of solar dryer. The flowers were subjected to constant temperature and higher drying rate in the dryer throughout the drying process which reduces the effect of size reduction. The unutilized fresh flowers from domestic trade can be converted into value added products after drying in the solar dryer to enable get better returns.

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