Hybrid solar dryer for drying of high-value flowers

The world energy crisis has now given importance to solar energy utilization, research and development programmes all over the world. The sun is the largest fusion reactor known to mankind which supplies about 1000 times more energy than we need each day in the form of electromagnetic radiations. In order to harness solar energy, a dark surface is exposed to solar radiation so that it is absorbed[1]. Two main approaches currently in use to harness solar energy are converting it to electricity by photovoltaic approach and converting it to thermal energy by 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. The efficient utilization of solar energy for heating, cooling and process applications requires the use of flat-plate or even focusing collector systems which first receive, as much as possible, the incoming solar radiation and then deliver a large fraction of the thermal energy to the working fluid[2]. The flat-plate collector is the key component of any solar energy system.

Dried or dehydrated flowers or plant parts or botanicals (root, leaf, stem, bark or whole plant) can be used for ornamental purposes. Flower drying is an important post-harvest technique for enhancing keeping quality and providing value addition. The flower-drying technique involves reducing moisture content of flowers to a point at which biochemical changes are minimized while maintaining cell structure, pigment level and flower shape[3].

In floriculture trade, fresh flowers constitute a major part but due to their reduced shelf-life, flowers remain fresh only for a short duration. Therefore, to overcome this problem, techniques of dehydration and drying play a vital role. Dried flowers and plant parts constitute 70% of the total share of floriculture products export from India[4]. However, the country's share in dry flower industry is below 5% of the global market[5].

Drying leads to reduced microbial activity and ageing effect. The dried flowers can be stored in moisture-free atmosphere for longer periods without losing their appearance and decorative value. Thus, the flowers are not dependent on seasons[6]. Only a few research and development projects have been undertaken in the flower drying industry across the globe, in contrast to other areas of floriculture, due to the unavailability of improved dryers. The demand for dry flower and attractive plants (part dried) for floral arrangement and floral crafts has increased manifold during the last decade. The demand for dry flowers is increasing at an impressive rate of 8–10% annually, thus offering good opportunity for Indian entrepreneurs to enter the global floriculture trade[5].

Dry flowers that are near natural, dried and preserved have an everlasting value that can be cherished for longer periods and require little care. Dry flower market has grown exponentially as consumers have become 'eco-conscious', and choose dried flowers as they are eco-friendly and a biodegradable alternative to fresh flowers.

There is large potential to develop the dry flower industry in India and to provide employment to housewives, unemployed youth and rural women. Simplified indigenous techniques have been developed by which flowers, branches, twigs, foliage, etc. retain their freshness for several months or even years. The original shape, colour and size before dehydration are retained, thus, making them highly suitable raw materials for interior decoration. Dehydrated flowers and foliage can be used for designing artistic decorative items, e.g. greeting cards, wall plates, calendars, landscapes, etc.

In view of the above, a hybrid solar dryer has been developed in this study for high-value flowers such as rose and marigold.

A hybrid solar dryer was fabricated with galvanized iron (GI) sheet, mild steel (MS) sheet, angle iron, grill, etc. The dryer has two chambers, namely heating chamber and drying chamber. The size of the heating chamber is 1.22 m × 1 m × 0.94 m having volume of 0.47 m^3 (Figure 1). The size of the drying chamber is 0.93 m × 1 m × 0.6 m having volume of 0.56 m^3. Overall total volume of the dryer is 1.04 m^3. The drying chamber has four sections for storage of the material to be dried. Each portion has an area of 0.57 m^2 and the total storage area is 3.4 m^2. The dryer is provided with a glass cover of dimensions 1.2 m × 0.91 m for allowing solar radiation to enter into it for heating. The inner portion of the dryer is painted black to increase the absorptivity of the solar radiation. Approximately 500 kg of round stone pebbles of 0.1–0.13 m is provided in the heating chamber to act as rock-bed storage of the solar radiation during day and provide some heating to the drying chamber during night in the absence of solar radiation. These pebbles have been painted black so that maximum solar radiation is absorbed to give more heat. A chimney of size 0.9 m and diameter 0.26 m has been provided at the centre of the drying chamber for ventilation of the dryer and removal of moist air. Three 12 V and 3 W DC exhaust fans are provided at the bottom of the drying chamber to draw thermal heat from the heating chamber and supply it to the drying chamber for faster drying of the material. These fans are operated with the help of a 12 V/100 W solar photovoltaic (SPV)

Figure 1. View of hybrid solar dryer, drying chamber and fans.

Figure 2. Tagging of flower samples before embedding.

Figure 3. Stages of embedding the flower samples.

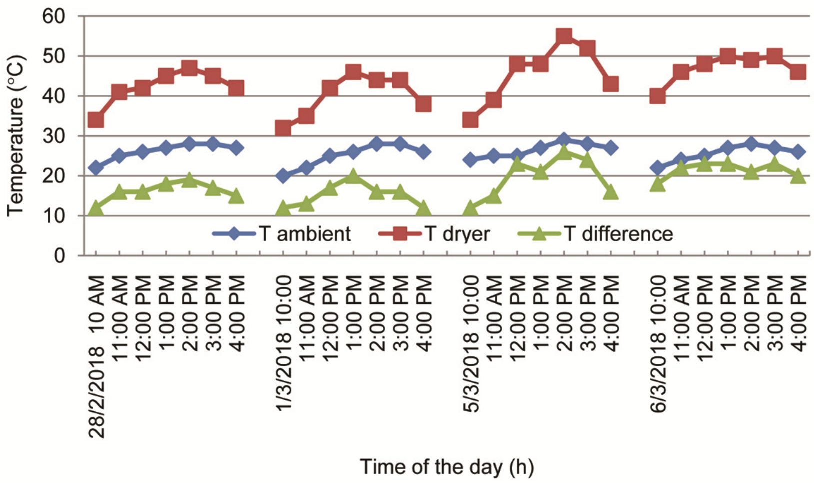

Figure 4. Hourly variation of ambient temperature and dryer temperature.

panel or battery. Being a hybrid solar dryer, it works on solar thermal and SPV system. A 12 V battery can also be used which can be charged during the day with the help of solar radiation, and during night when the ambient temperature is low, these fans can be operated using battery. Thus it is basically a zero-energy dryer working on renewable source of energy alone.

For sample preparation, the leaves and stalks were separated from freshly procured flowers (rose and marigold of variety Tajmahal and Kolkata orange respectively) before the tests. Properties like diameter, height and initial weight were recorded for each sample and respective tags were attached to them. Five flowers from each lot were used to determine the initial moisture content (wb) of the lot. For this, the flowers were dried in a microwave oven for 3–4 min, until they became bone dry[7]. Once the samples were ready, they were embedded in silica gel.

Embedding of flowers was done according to the standard method[8]. A layer of 2.5 cm of silica gel was laid in the tray (Figure 2). The flowers were gently placed on this layer. Silica gel was then poured slowly around the flowers till the height of flowers in the tray is covered. The tray was tapped and shaken so that silica gel settled properly around the flowers. The gel was then poured gently on the top of flowers so that it spreads between the layers of petals (Figure 3). Finally a layer of 1.5 cm of silica gel was placed above the flowers and thus the flowers were embedded.

The hourly ambient temperature and dryer temperature were recorded (Figure 4). The temperature in the dryer was significantly higher than the ambient and the maximum temperature difference was found up to 26°C (Figure 4). When the flowers dried using the solar dryer were compared with those dried under the sun (control), it was found that the former exhibited superior quality in terms of all the parameters such as shape, texture, brittleness, colour, anthocyanin and carotenoid content (Table 1). 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 evaluation. Different properties like shape, colour, texture, intactness and brittleness were evaluated by a panel of five members. Each treatment was

Table 1. Mean values of different parameters of control and solar-dried (using the solar dryer) samples for rose and marigold

	Rose		Marigold	
Parameters	Control	Solar-dried	Control	Solar-dried
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	2.86	1	2.86
Colour	1.3	3.86	1.13	3.93
Intactness	83.33	100	80	100
Brittleness	3.93	1.06	4	1.86
Texture	1.06	3.86	1.06	3.13

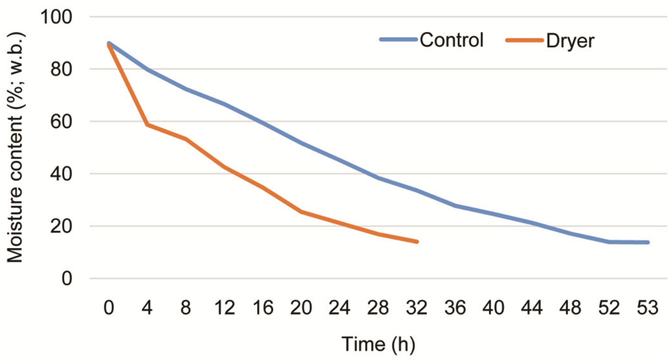

Figure 5. Hourly variation of moisture content (%) for rose flowers in the solar dryer and open sun.

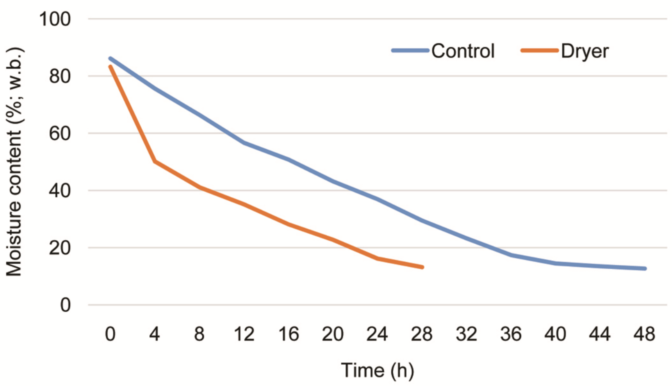

Figure 6. Hourly variation of moisture content (%) for marigold flowers in the solar dryer and open sun.

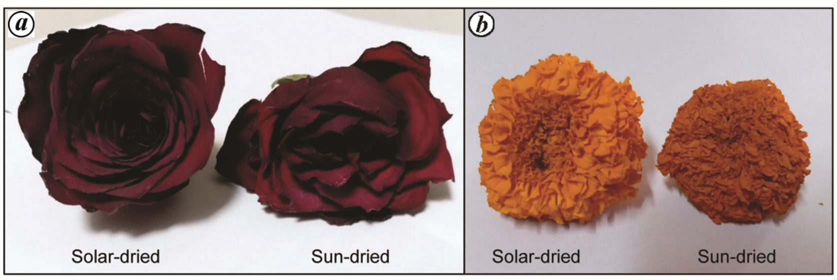

Figure 7. Solar-dried (using the solar dryer) and open sun-dried samples of (***a***) rose and (***b***) marigold flowers.

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.*[9].

Colour: 1 – Not acceptable, 2 – less acceptable, 3 – acceptable, 4 – highly acceptable.

Shape: 1 – Distorted, 2 – maintained, 3 – very well maintained.

Intactness: 100% – No damage, 90% – 0%–10% damage, 80% – 10% to 20% damage.

Texture: 1 – Not acceptable, 2 – less acceptable, 3 – acceptable, 4 – highly acceptable.

Brittleness: 1 – Very low, 2 – low, 3 – moderate, 4 – high.

As the temperature inside the dryer is fairly constant throughout the drying process and shields the flowers from direct solar radiation, the drying rate for both types of flowers was found to be higher than that in the control. Thus the drying time reduced by 65% and 70% for rose and marigold flowers respectively, when the flowers were dried using the solar dryer (Figures 5 and 6). As the ambient temperature varies throughout the day, with solar intensity reaching maximum at noon, the quality parameters like shape, texture, brittleness, colour, anthocyanin and carotenoid content were adversely affected in case of flowers dried in open sun (Figure 7). The petals of control (open sun-dried) flowers developed cracks and undesirable texture. Petal fall was higher as the sample was subjected to prolonged period of drying, thus reducing the intactness score considerably. Due to the presence of light and high temperature of incident solar radiation, the anthocyanin and carotenoid stability was disturbed and lower retention of the same was found in the control. The presence of ultraviolet rays also degrades these pigments. The amount of all trans-β-carotene was highly reduced in open sun-drying, whereas significantly higher retentions were observed in flowers dried using the solar dryer (Figure 7).

The self-help groups, women and other small-scale entrepreneurs can tap the potential of dry flower trade using mixed-mode solar dryer with relatively less initial investment. The flowers dried using the solar dryer provides superior quality products and better overall acceptability compared to open sun-drying under embedded condition. The time of drying in a solar dryer was found to reduce by 65% and 70% for rose and marigold flowers respectively, than those dried in open sun. The effect of dust and loss of silica gel due to wind is also reduced by using the solar dryer. The flowers are subjected to constant temperature and higher drying rate throughout the drying process in the dryer, which minimize 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 for better returns. Besides flowers, this hybrid dryer can also be successfully used for the drying of other high-value crops/vegetables/spices/herbs.

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Occurrence of leaf tip mutation in black pepper (*Piper nigrum* L.)

Black pepper (*Piper nigrum* L., family: Piperaceae) is one of the oldest and most widely used culinary spices. Conventionally leaves of black pepper plant have a single acuminate or mucronate tip[1], but we found multiple tips in some black pepper plants. Panniyur-5 is a variety bred at the Pepper Research Station Panniyur by Kerala Agricultural University, Thrissur, India. It is a selection from open pollinated seedling progeny of Perumkodi with moderate susceptibility to foot rot disease at nursery[2]. Horticulture Section of ICAR-Central Coastal Agricultural Research Institute is engaged in research of black pepper as suitable inter/mixed crop in perennial crop-based cropping systems.

We observed some of the orthotropic stems of black pepper vine of one open pollinated seedling progeny of Panniyur-5 and their clonal progenies to display a rare leaf shape mutation with lobed leaf at tip. Mutations in leaf shape of 10 adult plants out of 330 plants were observed and studied in leaves of black pepper. Shape of the leaf varies among the pepper germplasm accessions and used as one of the descriptor traits to characterize the variation. Shape of the leaves of the pepper plants varies from ovate, ovate-lanceolate, ovate-elliptic, cordate, obovate, lanceolate, elliptic, ovate or broadly obovate[1,3].

All the mutant leaves studied possessed more than one tip and a broader leaf blade (Figure 1). Acuminate or drip tip is an adaptive feature in leaves of most tropical rain forest plants[4,5] to rapidly drip off water for natural drying of leaves. *Piper sagittifolium* is another species which has lobes at base[6] of the leaf. *Piper nigrum* L. does not possess any lobe at base or at tip as per the DUS descriptors[3].

About seventy mutant leaves were selected at random on the mutant plants. Another seventy leaves of similar age and position were selected on neighbouring plants of wild type. Inter nodal length, length and width of leaf, length and girth of petiole were measured. Pair of 10 wild type and mutant leaves were scanned on a flatbed scanner and the image was saved at 600 dpi as jpeg file. ImageJ software[7] with LeafJ plugin[8] was used to analyse the image files for measuring angle, circularity ($4 * \pi r^2$/(perimeter)^2), ferret diameter, ferret angle, roundedness and solidity (area/convex area)[7]. Paired *t*-test was performed using graphpad web service[9] to compare mean of the traits of mutant and wild-type plants for statistical significance.

Mean, range and variation values of leaf, petiole and internodal length of mutant and wild type are presented in Table 1. Leaf arrangement was opposite in some of the mutant leaves (Supplementary Figure 1). Leaves of the mutant plants possessed significantly larger leaf area than wild type (Table 1). Leaves of black pepper are simple and arranged alternate. Mutant leaves differed (Supplementary Table 1) based on number of tips, degree of fusion of leaves and changes in leaf arrangement (Supplementary Figure 1). Rooted cuttings with all mutant leaves having more than one acuminate tip (Figure 1) were selected and planted for further evaluation.

The long acuminate or the drip tip of the *Piper* leaves[5] was experimented to support leaf drainage in high rainfall regions. The water film due to excess rain fall held on the leaf surface if not drained can impact transpiration leading to decreased nutrient uptake[10]. The mutant leaf is able to drain water more effectively than wild type plants due to additional tips. Effective leaf size or leaf width of lobes/leaflets is known to increase due to increase in rainfall, but decrease with

Figure 1. Rooted cutting of mutant black pepper with modified leaf tip.