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RESEARCH ARTICLE

Performance evaluation of solar cabinet and tunnel dryer for drying agro-commodity: A comparative study

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ABSTRACT

Solar drying is the traditional method of preserving fruits, crops and vegetables. It is an alternate strategy for avoiding a natural resource deficit. However, traditional sun drying degrades food quality and is ineffective in preventing dust, other insects, or birds. For this reason, this article represents suitable post-harvest solar dryer technology for 4kg of tomato drying. In this study, two different solar dryers, viz. indirect solar cabinet dryer (SCD) and direct solar tunnel dryer (STD) of the same aperture area, were examined simultaneously under the environmental conditions of Nashik, India. After 12 hours of drying time in two days experiment, the moisture content of tomato slices inside of tunnel dryer is 15.1% (w.b.); meanwhile, the cabinet dryer is still 53% (w.b.). The result showed that both dryers produce a drying air temperature of 45-67^{0}C, which is suitable for drying almost all agro-commodities. The average thermal efficiency was 17% & 14% for solar cabinet dryers and 30% & 29% for solar tunnel dryers, respectively, in two days experiment. According to these results, solar tunnel dryer shows better performance in terms of average drying air temperature, thermal efficiency, moisture removal rate and quality of the dried product compared to solar cabinet dryer.

Keywords: Solar dryer, efficiency, tomato, moisture content.

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INTRODUCTION

Tomatoes are one of the important vegetables/fruits in our diet since they are rich in health-valued food components such as lycopene, ascorbic acid (vitamin C), vitamin E, and dietary fiber (Adsule et al., 2012). It is a versatile commodity that can be eaten fresh or processed to use in a comprehensive collection of products to improve flavour. Presently, the demand for tomatoes is increasing steadily with an increase in population and its likeliness towards tomatoes. India is the 4th major tomato-producing country in the world, next to China, U.S.A. and Turkey. Presently, India is the major exporter of tomatoes to Pakistan, Bangladesh, U.A.E., Nepal, Maldives and Oman. The world average yield of tomatoes is 23 tons per hectare. Indian average yield of tomato is 9.6 tons per hectare. Currently, spoilage of fresh tomatoes is significant; ultimately, the small-scale producers

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in India cannot match their products to high-value markets in urban areas (Patil and Gawande, 2016). Due to inadequate postharvest handling in the field, transit and storage, pathogenic mycoflora leads to processes of rot with consequent loss of products up to 30-40% in developing countries (Rai and Singh, 2022). Among the techniques developed during the past decades so far, solar drying systems have proven to be a practical and viable technology for addressing post-harvest issues (Hadi and Akbar, 2018). There are two methods to avoid spoilage and wastage of foodstuff, especially tomatoes. The first is the cold storage method, where the food will be stored in a highly refrigerated room, thereby enhancing the small-scale farmers to meet the sudden and high market demands without significant wastage. This method is expensive, and small-scale farmers need help to afford it. The second method is drying the product, which is the most appropriate solution for reducing spoilage, gaining prolonged shelf-life and enhancing the market value of the products, thereby allowing poor small-scale farmers to achieve profit. The drying process is the most significant form of food preservation and also for its extended shelf-life. It is a simultaneous heat and mass transfer process in which hot air removes moisture from the food material. Dried tomatoes are widely used in salads, pizzas and spicy dishes. They are also packed in canola oil with garlic, herbs and spices. Other uses for dried tomato include tomato spread, soups, sauces, salsa, pesto and many others (Patil and Kulkarni, 2022). Generally, all solar dryers work under active or passive mode. In active mode, the air is forced throughout a dryer and the product bed by a fan or a blower, commonly called forced convection dryers. On the other hand, in passive mode, the movement of hot air is induced due to temperature gradients.

Several examples can be found in the literature where plentiful, free, cleaner, and ecological solar thermal energy has been used for drying various wet biological materials. For example, solar drying technique has been used for drying potato slices (Samira et al., 2013), red pepper and grape (Aymen et al., 2015), cherry tomatoes (Nabnean et al., 2016), melon slices (Mustafa et al., 2016), banana slices (Lingayat et al., 2017), amla candy (Patil et al., 2022). From the accessible literature, solar cabinet and tunnel dryers were found to be the most practical post-harvest drying system for drying diverse agro-products. Therefore these two drying systems were preferred for investigation and to compare the drying kinetics of tomatoes in identical environmental conditions of Chandwad. The precise objective is to compare the thermal performance evaluation of both dryers for tomato drying.

MATERIALS AND METHODS

Materials

From the local market of Nashik, fresh tomatoes were purchased and washed with clean water to remove the dust particles. The identical size tomatoes were cut in slices (4-5mm) thickness using stainless steel knife to avoid surface blackening. Tomato is a vegetable/fruit of vast popularity and is considered hygroscopic material (Patil et al., 2016). The air oven method is used to find the tomato's initial moisture content, estimated as 80% (w.b). To improve the drying rate and quality of dried tomatoes, a pretreatment with potassium metabisulphate (KMS) solution is done for five minutes.

Details of dryers (SCD & STD) and experimental method

Fig. 1 shows the pictorial view for the indirect solar cabinet and direct solar tunnel dryer of identical aperture area. The solar cabinet dryer consists of an air heating unit (collector), a drying chamber with four trays, and a small fan to provide the required airflow rate for the product to be dried. The solar tunnel dryer comprises two tunnels of the same size with an aperture area of 2 m^2 each and is connected in series with a small rectangular opening for the movement of hot drying air through it. The dryer has the shape of a home cabinet with a tilted transparent glass top of 40^0 and has four trays in each tunnel.

(A)

(B)

Fig. 1. Experimental set up (A) Solar Cabinet Dryer & (B) Solar Tunnel Dryer

Both solar cabinet (SCD) and tunnel (STD) dryer having the same aperture area of 4 m^2 was tested simultaneously under the environmental conditions of Chandwad (latitude 20°31′N, longitude 74°25′E elevation 580m), India. Initially, both dryers were focused towards the sun and tested for no-load conditions to attain steady-state conditions. Later, the pretreated tomato slices (4-5mm) were loaded on all trays of both dryers for drying. The trials were conducted under forced convection mode between 9.30 am to 5.30 pm on sunny days of May 2023. During experimentation, tomato slices were dried up to the final moisture content of 15% (w.b).

Instrumentation

The drying air temperatures at various locations in both dryers were measured using PT100 thermocouples (accuracy 0.5^{0}C). A digital solar meter with 10% accuracy was used to measure the solar insolation. Both the wind speed and the hot air flow rate through the dryer were measured using the anemometer. A digital hygrometer with 10% accuracy was used to measure the relative humidity of the humid air. The product's moisture content was measured using a digital weighing balance (Capacity: 5 kg & Accuracy: 0.01 g). Drying air temperatures were recorded on a 16 Sunpro channel data recorder at intervals of 10 minutes.

Performance evaluation of SCD and STD

The performance of both STD and SCD was estimated in terms of drying air temperature, moisture content variation, drying efficiency and drying time. The performance evaluation results will identify the most effective solar drying system among solar cabinet and tunnel dryers.

Drying air temperature: The temperature required for a particular agro-product to be considered an essential aspect of designing a solar dryer. The drying air temperature in the range of 60-70^{0}C is crucial for the effective drying of agro-product (Patil et al., 2022). It mainly depends on the intensity of solar insolation and the mass flow rate of air flowing through the dryer. Too low drying air temperature cannot remove the correct amount of moisture content and deteriorates the dried product, while too high-temperature results in the hardening of the product. Hence the adequate drying air temperature throughout the drying chamber is the main challenge in designing a solar drying system.

The airflow rate through the solar collector was estimated by using the following equation (Lingayat et al., 2017):

$$m_a = \rho_a \times A_{inlet} \times v_a \quad (1)$$

Where m_a is mass of air circulated in dryer; A_{inlet} is area for airflow, and v_a is the velocity of air flowing through the dryer.

Moisture content variation: Almost all agro-products contain moisture, and the amount of moisture content present in a product can be expressed on a wet basis (% w.b) and dry basis (% d.b). The moisture content of any material is expressed conveniently on a dry basis, but for agricultural products, the moisture content is indicated on a wet basis. Many methods can measure the amount of moisture content in a material, and the commonly used method for measuring the moisture content in an agricultural product is an oven-drying method. About 2000 grams of identical tomato slices were kept on each tray of both dryers. The initial and final mass of samples is recorded using a digital electronic weighing balance at every 1-hour time interval till the end of drying. Moisture content on a wet basis was calculated using the following equation (Patil and Kulkarni, 2022):

$$M_{wb} = \frac{W_0 - W_d}{W_0} \quad (2)$$

Where M_{wb} is moisture content in % w.b; W_0 is the initial weight of undried produce; W_d is weight of dry matter in produce.

The rate of moisture movement from the product inside to the air outside differs from one product to another and very much depends on whether the material is hygroscopic or non-hygroscopic.

Efficiency: The collector efficiency of SCD is the ratio of heat received by the drying air to the heat incident on the collector's absorber surface and estimated using the following equation (Lingayat et al., 2017):

$$\eta_{Collector} = \frac{m_a \times C_{Pa} \times \Delta T}{A_{aperture} \times I \times Transmitivity} \quad (3)$$

Where C_{Pa} is specific heat of air; $A_{aperture}$ is area on which solar insolation strikes; I is solar insolation, and ΔT is air temperature difference in the collector.

The amount of heat required to evaporate the product's moisture is called drying efficiency. The sensible and latent heats are responsible for evaporating the water from the core of the product and estimated by using the following equation (Aymen et al., 2015):

$$\eta_{dryer} = \frac{m_P \times C_{Pa} \times (T_P - T_{avg}.) + (m_w \times h_{fg})}{(A_{aperture} \times I \times \text{Transmitivity}) + P_f} \quad (4)$$

$$m_v = M_i - M_f$$

$$m_v = \frac{\text{Initial weight} \times (\text{Initial moisture content - Final moisture content})}{(\text{100 - Final moisture content})} \quad (5)$$

Where m_p and m_w are mass of product and moisture evaporated, T_p and T_{avg} are temperature of surface of product and average drying air temperature in the drying chamber, and hfg is latent heat required for evaporation of moisture.

Drying rate: The drying rate depends only on the material's properties to be dried, its size, the drying air temperature, and the moisture content. Low drying air temperature, large size and higher moisture content of product results in slow drying and thus requires more drying time. The drying time for the high moisture content product can be minimized by maintaining adequate drying air temperature and the size of the product.

RESULTS AND DISCUSSION

Fig. 2 and Table 1 compare the average drying air temperature in SCD and STD against drying time. In the morning, above temperatures start to go up, reach a maximum value at noon and later go down in the evening. The variation in ambient and drying air temperature in the dryer was found in the range of 30-36 ^{0}C, 36-58 ^{0}C (SCD) & 48-63^{0}C (STD), respectively. The result shows that the drying air temperature is suitable for removing the surplus water from the commodity.

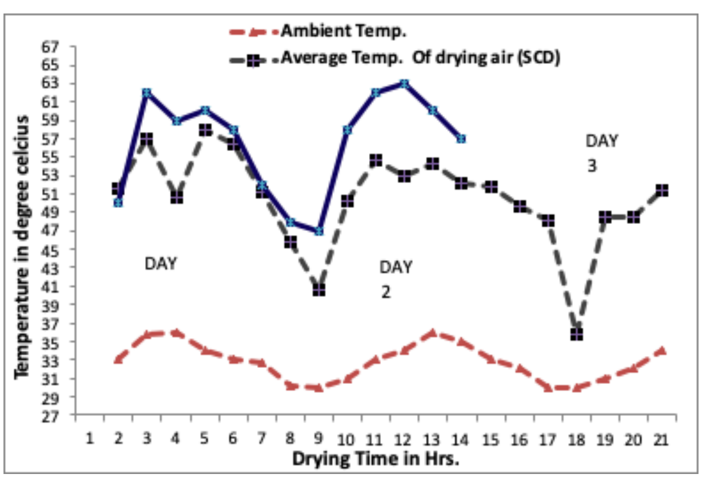

Fig. 2. Variation of ambient and drying air temperature against drying time

Table 1. Comparative results for drying of tomato slices

Particulars	SCD	STD
Average drying air temperature		
DAY 1	57 ^{0}C	63 ^{0}C
DAY 2	55 ^{0}C	61 ^{0}C
DAY 3	57 ^{0}C	Not Applicable
% of average moisture removal		
DAY 1	69	76
DAY 2	47	52
DAY 3	31	
Average drying efficiency		
DAY 1	17%	30%
DAY 2	14%	29%
DAY 3	12%	Not Applicable
Drying time (Hour)	19	12

Variation of moisture content during drying time

Fig. 3 demonstrates the comparison of variation of moisture content in SCD and STD against drying time. The water content of tomato slices was reduced from 80% (w.b.) to 15% (w.b.) within three days (19 hours) in SCD, whereas STD requires 12 hours to remove the same moisture content. Hence the moisture removal rate of STD is much better than SCD due to better circulation of adequate drying air throughout the drying chamber and better construction. The result shows that the moisture extraction rate rises and falls as drying progresses. Initially, the moisture present on the outer surface is extracted rapidly and later on, heat in drying air extracts the water from the product's interior. The above results show that the entire drying course occurs in the falling rate period, and moisture content diminishes continuously with increasing drying time.

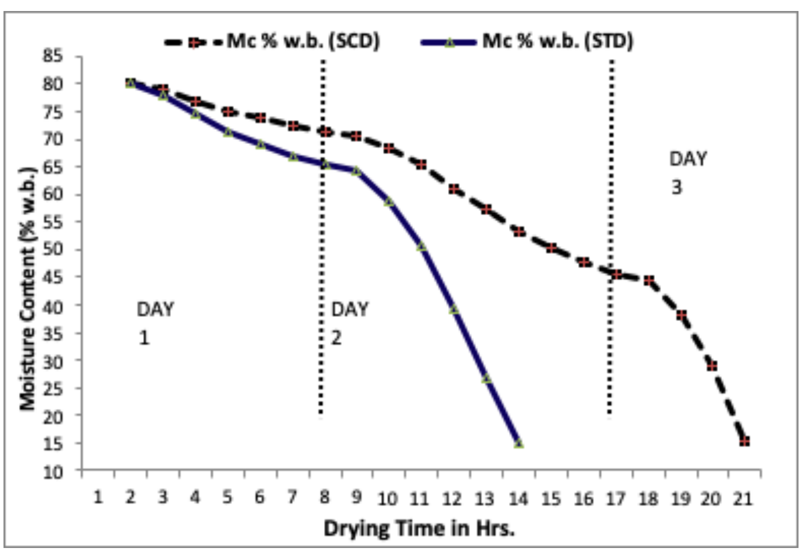

Fig. 3. Variation of moisture content (% w.b.) against drying time

Dryer efficiency

Fig. 4 compares dryer efficiency against the drying time for tomato slices. The average dryer efficiency for SCD and STD was 17% & 30% on the first drying day and went down in succeeding days. The higher values of dryer efficiency during the first hours/days of drying were due to the effectual utilization of useful energy and more moisture extraction from the product. The exponential relationship between drying efficiency and drying time has been observed. The dryer efficiency of STD is more than SCD due to high drying air temperature, air movement through tunnels and trays and excellent manufacturability. The results proved that the capacity of drying air in the vaporization of water from the commodity is adequate.

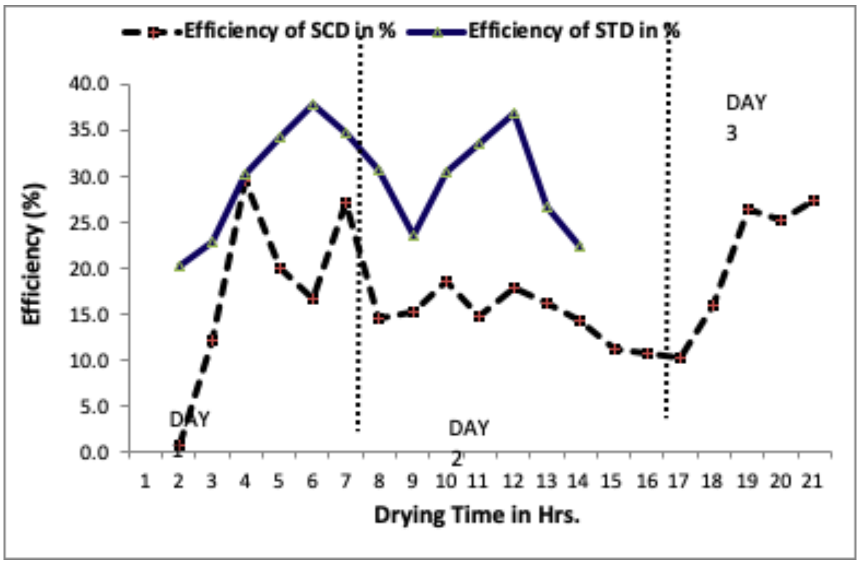

Fig. 4. Variation of dryer efficiency against drying time

CONCLUSION

The conclusions drawn from the comparative study may be summarized as follows:

1. The moisture content of tomato slices was reduced from 80% to 15% w.b in 19 hours for the solar cabinet drying, whereas the solar tunnel dryer took only 12 hours. It is due to the high drying temperature, better air movement, construction and easy tracking of the dryer.
2. The SCD and STD heat the drying air adequately to increase its capacity in favour of taking up moisture from the product.
3. The tunnel dryer's efficiency is 15% more than the solar cabinet dryer during the tomato drying experiment.
4. A forced convection solar tunnel dryer is more suitable for producing high-value dried tomatoes for small landholder farmers.

This comparative study might be helpful for end users to select an appropriate mode of solar drying for drying different agro commodities. Finally, solar drying postharvest technology forms an essential component of the agricultural supply chain. This ensures that farmers and consumers benefit from its efficient implementation, which leads to a decrease in losses, an increase in food security, increases in income and the sustainability of development.

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