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# Performance Evaluation of Solar Dryers for Drying of Red Chilli (*Capsicum annuum*)

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## ABSTRACT

Red chilli, one of the most essential spices in the Indian house hold is a critical crop for the farmers. Drying of red chilli is an important unit operation done before marketing. The variation in the market price of dried chilli depends majorly on its external color appearance. Open field drying on the earthen ground, which is a common rural practice, tends to decolor the chilli besides rendering an erratic variations in moisture removal. Hence, in present study, two commercial solar dryers namely, Box type hybrid energy solar dryer ($T_1$), Convective solar dryer ($T_2$) were evaluated and drying process was compared with conventional methods such as Drying on Tarpaulin Sheet ($T_3$) and Drying on the Earthen Ground ($T_4$). Drying experiments were conducted during December 2022 and January 2023 with freshly harvested red chilli fruits (var Byadagi dabbi). The results have shown that, an average temperature of 43.60 and 38.30 $^oC$ were achieved in $T_1$ and $T_2$ respectively while the average ambient temperature recorded was 25.10 $^oC$. It took 4 days for complete drying of chilli samples in $T_1$ whereas $T_2$, $T_3$ and $T_4$ required 6, 10 and 12 days, respectively. Moisture content of dried chilli samples (wb) and moisture removal rate (MRR) for $T_1$ were 0.90 % and 2.73 kg/day, respectively. In case of $T_2$, it was 1.40 % and 1.63 kg/day, respectively. It was 1.80 % and 0.92 kg/day, respectively for $T_3$. In case of $T_4$, it was 2.30 % and 0.79 kg/day, respectively. Regression analysis for all the treatments revealed that insolation and moisture content were negatively related whereas insolation and Cumulative MRR were positively related. $T_1$ has shown the best performance with predicted $R^2$ value of 0.9740.

**Keywords** Red chilli, Byadagi dabbi, Drying, moisture removal rate, Regression.

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## INTRODUCTION

Chilli is one of the major spices crops in India. “Byadagi chilli” is a popular variety of red chilli grown in North Karnataka Districts namely Haveri, Gadag and Dharwad under rainfed conditions. Byadagi chillies are of two types viz., Dabbi and Kaddi. Byadagi dabbi is small and plump and it is characterized by its color, flavor and taste. Even though it has more seeds in it, it is less pungent compared to the kaddi variety. This variety is best suited for preparation of masala and extraction of oleoresin. The Byadagi kaddi type is gnarled, thin and long with fewer seeds. Byadagi chilli is mainly used in manufacturing of nail polish and lipstick in cosmetic industry. Byadgi chillies have been tagged with Geographical Indication (GI application No. 129) product of Karnataka. It is primarily marketed in Byadagi chilli market with annual sales of about Rs 600 Crores (Anon 2022).

Chillies are perishable in nature. Hence they require more attention in safe handling during harvest, storage and transportation. Harvesting should be done at the right stage of maturity and it depends on the market demand. Dried chilli constitutes a major share of consumption among the spices. Byadgi chillies, during harvesting, will have moisture content of 65 to 80% (wb) depending on whether partially dried on the plant or harvested while they are still succulent. They are then dried in the sunlight to retain the color and restrict microbial growth by spreading on clean dry polythene sheets / tarpaulin sheets, on concrete drying yards or on the earthen ground. Pods are spread out in thin layers for uniform drying and frequent stirring would be done to prevent mould growth and discolouration. The dried pods are heaped and covered by clean gunny bags / polythene sheets.

The open yard drying of red chillies, by traditional practice often tends to reduce the red color of chillies resulting in low market price. Drying by conventional sun drying procedure takes 8 to 15 days depending on prevailing weather and temperature and about 25 to 30 kg of sun dried chilli is obtained from 100 kg of fresh fruits (Anon 2012). Since Byadagi chilli is harvested during the months of December-January, the ambient temperature will be on lower side and requires more exposure time for effective drying of chillies. Moreover, the chilli powder made with the open sun dried chillies tends to have white color and fetch less market price. Hence, there is a need for technological intervention in drying of red chillies without losing the color, quality and economic value. Solar dryers, which are hygienic way of drying food products compared to the traditional sun or shade drying methods, enable the drying parameters to be controlled and also provide more uniform drying in a shorter time (Asnaz 2022).

Most of the solar dryers work on the principle of green house gas effect. The drying process in the solar dryer involves retaining the heat energy received from sunlight in order to increase the temperature of drying space. Many of the food products are hygroscopic in nature and the moisture stored in them will be removed by the process of mass transfer so as to maintain equilibrium moisture content with the surrounding space. The moisture removed in such way will be removed from the dryer through exhaust fans. There are numerous solar dryers developed in various parts of the country for drying of different food commodities including red chilli. Solar tunnel dryer is one such technology which is used extensively for drying of different commodities including red chilli on large scale. Tunnel dryers are available in various capacities starting from 0.5 tonnes up to 5 tonnes per day. Apart from tunnel dryers, there are many batch type and solar cabinet dryers developed and popularized for drying of chillies at small scale with capacity varying between 5 and 50 kg/day.

Various studies have been conducted globally regarding different drying technologies for different commodities. Red chilli, being one of those food products which exhibit higher hygroscopicity, needs to be dried as early as possible for safe storage. Tunde-Akintunde (2011) investigated the drying characteristics of chilli pepper namely moisture ratio, drying rate and drying time. Sun drying was taken as control and a direct solar dryer was used for the experiment. Author has fitted four thin-layer drying models (Newton, Henderson and Pabis, Logarithmic and Page) to the experimental data to arrive at the suitable drying equation. The Page model was found to best describe the drying behavior of chilli pepper for sun and solar drying. Kilanko *et al.* (2019) designed and evaluated a direct heating type solar dryer for drying of bonnet pepper. The authors concluded that the temperature in the dryer was higer when compared to surrounding between 10 AM to 6 PM. Average moisture content of 81.30 % (wb) was removed from the pepper during the entire course of experiment. The average efficiency of the designed dryer was 28.40 %.

Keeping in view the above facts and figures, present study was conducted to evaluate two different solar dryers for drying of red chillies (Byadagi variety) and the comparative studies were conducted with conventional drying methods viz., tarpaulin drying method and drying on the earthen ground.

## MATERIALS AND METHODS

The quality of dried red chillies is of utmost importance for market acceptability and value addition purpose. Color, texture, flavor and pungency are the important characteristics of red chilli that are directly influenced by the moisture content.

In present study, two types of solar dryers were evaluated for drying of chilli and their performance parameters were compared with tarpaulin method and traditional method of drying. Both the dryers work on the principle of green house gas effect. The air inside the drying chamber is heated by arresting the sun light, thus increasing the temperature. Moisture from the chilli fruits is absorbed by the heated air. Solar photovoltaic panels were used to generate electricity to drive the fans which expel the heated air out of the dryers.

### Location and evaluation conditions

Solar dryers were evaluated at a farmer's field near Kurtakoti village (15.38°N, 75.53°E) during 28th December, 2022 to 09th January, 2023. Freshly harvested red chilli fruits (var Byadagi dabbi) were used for the evaluation. The weather parameters such as insolation, temperature and relative humidity of the study location were recorded during the period of study and are shown in Table 1.

**Table 1.** Meteorological parameters of study location (daily average).

| Sl. No. | Date | Insolation ($W/m^2$) | Temperature (°C) | Relative humidity (%) |
|---|---|---|---|---|
| 1 | 29/12/2022 | 10.84 | 23.10 | 69.00 |
| 2 | 30/12/2022 | 11.91 | 24.50 | 67.00 |
| 3 | 31/12/2022 | 9.01 | 26.40 | 75.70 |
| 4 | 01/01/2023 | 9.63 | 23.30 | 73.80 |
| 5 | 02/01/2023 | 11.26 | 22.90 | 69.60 |
| 6 | 03/01/2023 | 10.17 | 25.50 | 71.30 |
| 7 | 04/01/2023 | 11.12 | 23.60 | 68.20 |
| 8 | 05/01/2023 | 11.11 | 22.40 | 66.30 |
| 9 | 06/01/2023 | 10.26 | 22.60 | 68.40 |
| 10 | 07/01/2023 | 11.05 | 22.10 | 67.00 |
| 11 | 08/01/2023 | 9.95 | 23.20 | 67.80 |
| 12 | 09/01/2023 | 10.39 | 24.10 | 65.90 |

### Description of solar dryers

Two commercially available solar dryers of different designs with similar principle of operation were selected for the study. Some of the important technical specifications of both the selected dryers are enlisted in Table 2.

***Box type hybrid energy solar dryer:*** This dryer was made of aluminium material with a transparent poly carbonate sheet cover on top. It had six exhaust fans to expel the heated air out of the drying chamber that are powered by the solar PV panel of 50 W capacity. In addition, it was also having provision for connecting to the domestic electric source so as to keep the fans running even during low solar intensity. The dryer is also equipped with an electric space heating device which can be used to increase the rate of heating the air. There were 12 number of perforated trays stalked in the drying chamber with 75 mm vertical spacing. The total capacity of the dryer was 50 kg of fresh ripened chilli fruits (Fig. 1).

**Table 2.** Technical specifications of solar dryers.

| Sl. No. | Parameters | Box type hybrid energy solar dryer | Convective solar dryer |
|---|---|---|---|
| 1 | Material of construction | Aluminium | Galvanized iron |
| 2 | Drying capacity (kg/day) | 50 | 20 |
| 3 | Number of trays | 12 | 03 |
| 4 | Material of top cover | Poly carbonate | Polythene |
| 5 | Number of ventilation fans | 06 | 02 |
| 6 | Maximum temperature (°C) | 51 | 42 |
| 7 | Capacity of solar PV panel (W) | 50 | 40 |
| 8 | Overall dimensions | | |
| | Length, m | 3.05 | 2.16 |
| | Width, m | 0.92 | 1.88 |
| | Height, m | 1.05 | 1.23 |
| | Weight, kg | 320 | 80 |

**Fig. 1.** Box type hybrid energy solar dryer.

***Convective solar dryer:*** It was made of galvanized iron material and had a detachable frame. A polythene sheet was used to cover the drying chamber in which three perforated trays were placed to hold the chilli samples. The polythene sheet was responsible to create green house effect in the chamber, thereby increasing the temperature of the chamber. An exhaust fan, connected to a solar PV panel of 40 W capacity was fixed at one end. The total capacity of the dryer was 20 kg of fresh ripened chilli fruits (Fig. 2).

**Comparative evaluation of solar dryers**

The dryers were evaluated in a farmers' field of Kurtakoti village in Gadag block. Two types of dryers were considered as two treatments ($T_1$ and $T_2$) and the performance parameters were compared with tarpaulin drying method ($T_3$) and traditional method of drying on the earthen ground ($T_4$). 15 kg of fresh ripened chilli fruits was taken for evaluation for all the treatments.

**Fig. 2.** Convective solar dryer.

**Parameters**

Drying process is characterized by various parameters and there are numerous methods to study the drying parameters. In present study, some of the important performance parameters such as drying period, average drying temperature, moisture content of dried chilli samples and moisture removal rate were determined.

***Drying period***

It is the time period in days from the start of drying process till the final dried samples of chilli were obtained.

***Temperature***

It is the average temperature of drying chambers of solar dryers measured in °C. A probe type analogue thermometer was used to measure the temperature in the dryers. Ambient temperature was measured using a digital thermometer.

***Moisture content of dried chilli***

It is the amount of water present in the dried chilli samples. It was determined using oven dry method. A known weight of dried chilli samples ($W_i$) were kept in a hot air oven for 24 hrs at 105 °C. Dried weight of the samples was recorded after taking the chilli samples out of the oven ($W_d$). The moisture content on wet basis was expressed using following expression (Sahay and Singh 1994).

$$MC\ (wb) = \frac{W_i - W_d}{W_i} \times 100\ \%$$

where, MC = Moisture content (%), $W_i$ = Initial weight of the sample (g), $W_d$ = Dried weight of the sample (g).

***Moisture removal rate (MRR)***

It is the rate at which the moisture content from the chilli sample was removed. It was determined as the ratio of amount of moisture removed ($W_{MR}$) to the drying period (D), expressed in kg/day (Tunde-Akintunde 2011).

$$MRR = \frac{W_{MR}}{D}$$

**Regression analysis**

Regression analysis is generally used to establish relationship between one variable on the level of one or more other variables. Regression analysis, in general sense, means the prediction of the unknown value of one variable from the known value of the other variables (Liu *et al.* 2021). In present study, linear regression analysis was performed to analyze the effect insolation on moisture content of samples for all four treatments. For the ease of analysis, single day data of insolation and moisture content were collected with hourly interval. Minitab (v.19) statistical software was used to fit the regression model.

**RESULTS AND DISCUSSION**

Drying performance of Box type hybrid energy solar dryer ($T_1$), Convective solar dryer ($T_2$), Tarpaulin drying ($T_3$) and Drying on the earthen ground ($T_4$) were evaluated for red chilli. The results of the evaluation are presented as follows.

**Drying period**

The average drying period for $T_1$, $T_2$, $T_3$ and $T_4$ were recorded as 4, 6, 10 and 12 days respectively. $T_1$ performed well in comparison to all other treatments.

**Temperature**

Temperature inside the solar dryers was recorded using a probe type thermometer and ambient tem-

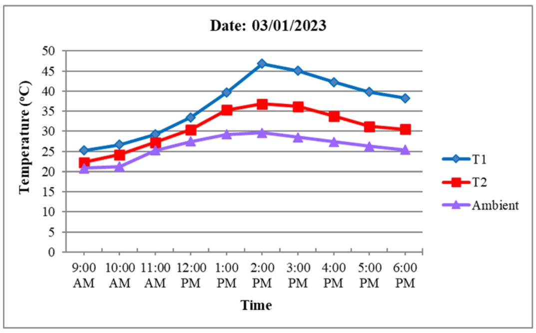


**Fig. 3.** Variation of hourly temperature for $T_1$, $T_2$ and ambient conditions.

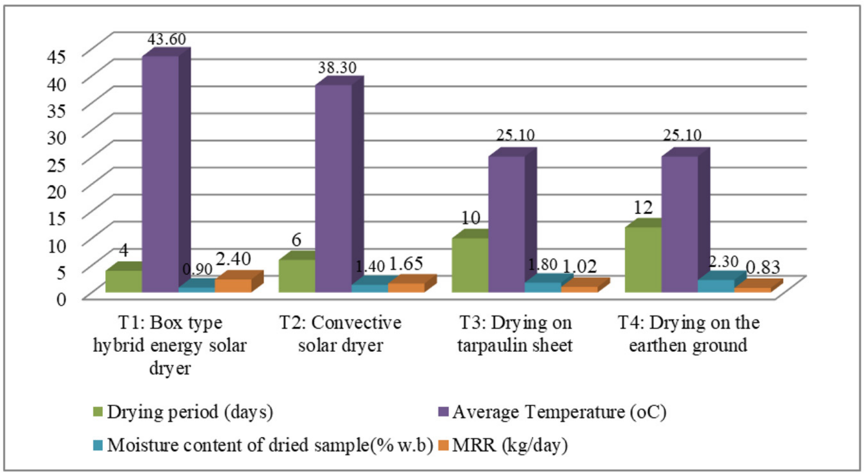


**Fig. 4.** Results of comparative evaluation of different drying methods.

perature was measured using a digital thermometer. There was significant rise in the temperatures inside the dryers. The average temperatures recorded for $T_1$, $T_2$, $T_3$ and $T_4$ were 43.60°C, 38.30°C, 25.10°C and 25.10°C, respectively (Fig. 3).

### Moisture content of dried chilli

Even though the chilli samples look completely dried by visible test, there bound to be some residual moisture. Hence, the moisture contents of dried samples were determined using hot air oven method for all four treatments. The average moisture contents of chilli in $T_1$, $T_2$, $T_3$ and $T_4$ were 0.90, 1.40, 1.80 and 2.30% (wb) respectively.

**Table 3.** Results of performance evaluation of different drying methods for red chilli.

| Sl. No. | Parameters | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|---|---|---|---|---|---|
| 1 | Initial weight (kg) | 15 | 15 | 15 | 15 |
| 2 | Final weight (kg) | 5.40 | 5.10 | 4.80 | 5.10 |
| 3 | Drying period (days) | 4 | 6 | 10 | 12 |
| 4 | Average temperature (°C) | 43.60 | 38.30 | 25.10 | 25.10 |
| 5 | Moisture content of dried sample (% wb) | 0.90 | 1.40 | 1.80 | 2.30 |
| 6 | MRR (kg/day) | 2.40 | 1.65 | 1.02 | 0.83 |

$T_1$ : Box type hybrid energy solar dryer
$T_2$ : Convective solar dryer
$T_3$ : Drying on tarpaulin sheet
$T_4$ : Drying on the earthen ground

### Moisture removal rate (MRR)

It is an important parameter to assess the expedition of drying process. Moisture removal rate (MRR) of all four treatments were worked out and it was found that MRR for $T_1$, $T_2$, $T_3$ and $T_4$ were 2.40, 1.65, 1.02 and 0.83 kg/day, respectively. Results of all the parameters are enlisted in Table 3 and graphically presented in Fig. 4.

### Relationship between insolation and moisture content

A linear regression model was fit to infer the relationships between insolation and moisture content for all four treatments under the study. Moisture content showed a negative linear relationship with insolation for all four treatments, which goes to suggest that moisture content evidently decreased with increase in the values of insolation (Fig. 5).

Value of coefficient of determination ($R^2$) for $T_1$ was 0.9845 which was close to the adjusted $R^2$ value of 0.9832 which indicates that regression model can be used to navigate the design space. The regression equation between insolation (I) and moisture content (MC) for $T_1$ is written as follows.

$$MC = 57.26 - 1.329\, I \qquad \ldots (1)$$

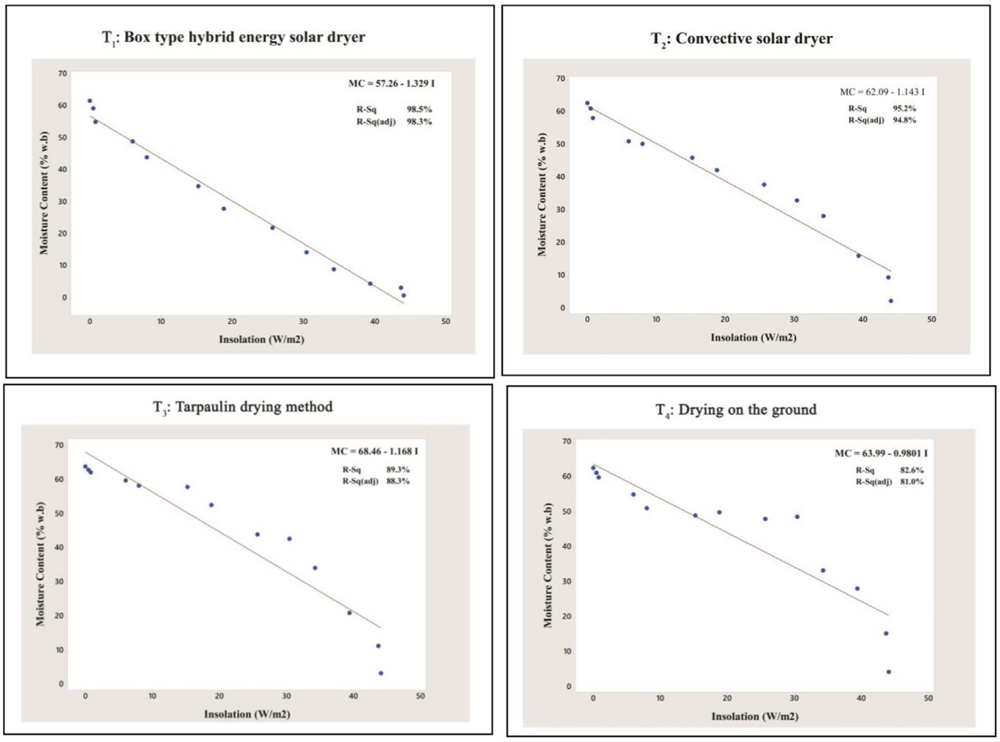


**Fig. 5.** Regression plots of insolation (I) against moisture content (MC).

$R^2$ value for Treatments $T_2$, $T_3$ and $T_4$ were 0.9532, 0.8934 and 0.8255. The degree of closeness of $R^2$ values to unity clearly indicate that the reduction in the value of moisture content of samples in $T_3$ and $T_4$ were not much uniform when compared to $T_1$ and $T_2$. There was erratic variation of moisture content depletion from the samples with insolation. This may be due to non-uniform moisture migration from the bottom layers of the chilli samples which are not completely exposed to the direct sunlight in case of $T_3$ and $T_4$. The regression equations for $T_2$, $T_3$ and $T_4$ are written as follows.

$T_2$: $MC = 62.09 – 1.143\ I$ … (2)

$T_3$: $MC = 68.46 – 1.168\ I$ ... (3)

$T_4$ : $MC = 63.99 – 0.9801\ I$ ... (4)

## CONCLUSION

Solar drying is one of the effective and hygienic methods of drying. Indirect solar drying method, using solar PV technology to circulate the air through the drying chamber has shown considerable success over direct drying method. Solar tunnel dryers of high capacity are not easily accessible for small and marginal farmers. Hence, it is need of the hour to popularize small scale box type or cabinet type convective dryers to perform drying of various commodities before marketing. In present study, two commercial solar dryers viz., Box type hybrid energy solar dryer ($T_1$) and Convective solar dryer ($T_2$) were considered for comparative evaluation with conventional drying methods namely tarpaulin drying method ($T_3$) and drying on the earthen ground ($T_4$). Results of the evaluation have shown that the box type hybrid energy solar dryer performed better when compared other three drying methods. Drying period was maximum for $T_4$ followed by $T_3$, $T_2$ and $T_1$. Moisture Removal Rate (MRR) was highest for $T_1$ followed by $T_2$, $T_3$ and $T_4$. Moisture content in dried chilli was highest in $T_4$ followed by $T_3$, $T_2$ and $T_1$. Loss of color and pungency was the least in $T_1$ when compared to other methods. Regression analysis revealed that the solar dryers performed better with $R^2$ values being near to unity. However, the regression models for all four treatments were significant at 1% confidence level, which show that moisture content decreased with increase in insolation. Moisture migration was comparatively non-uniform in case of $T_3$ and $T_4$ when compared to $T_1$ and $T_2$.

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