Research Article

Comparison Between Solar Tunnel, Solar-Cum Gas Dryer, and Open Sun Drying Methods for Drying Red Chilies

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Abstract | Chili is an important crop and spice produced in Pakistan and globally. In Pakistan, the Umerkot district is the primary producer of chili crops. In this area, the chili is being usually dry under the open sun (T3) or traditional method; this practice has many drawbacks and leads to poor quality. A study was planned to find an alternative chili drying method for the study area. To achieve the desired goal, we considered two different drying methods, solar tunnel (T1) and solar cum gas (T2), and compared the rate of reducing the moisture over time with T3 method. The T1 and T2 methods are substitutes for the T3 drying method. Therefore, a small-scale natural convection solar tunnel dryer and solar cum gas-based drying methods were developed and tested at PARC-Arid Zone Research Center, Umerkot. This study was conducted in three different intervals during November 2022, and each interval was replicated three times. In addition, the chilies samples were collected (uniform in color and size) from the farmer's field and brought to the experimental site. The experiment selected chili variety was Longi, and the initial weight of the all collected samples was 2000 g. The selected samples' initial moisture content was considered to be 80%. The test results showed that T1 and T2 methods significantly reduced the moisture compared to T3 method. T1 and T2 method reduced the moisture level from 80% (w.b) to about 10-12% (w.b) in 63 and 54 hrs, respectively, compared to 81 hrs taken by T3. However, the total aflatoxin content of T1, T2, and T3 were 1.4, 3.0, and 2.7 ppb, respectively. The measured values were below the recommended values of the aflatoxin. Based on the experiment result, it was concluded that the T2 and T2 drying methods are a better alternative for open sun drying and ensure product quality. These methods are not subjected to the weather conditions like the rainy season.

Received | December 28, 2022; **Accepted** | March 24, 2023; **Published** | March 27, 2023
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Citation | Meghwar, B.L., A. Khan, I.A. Lakhiar, A.A. Mirani, M.S. Daper and M.W. Kalroo. 2023. Comparison between solar tunnel, solar-cum gas dryer, and open sun drying methods for drying red chilies. *Pakistan Journal of Agricultural Research,* 36(1): 63-70.
DOI | https://dx.doi.org/10.17582/journal.pjar/2022/36.1.63.70
Keywords | Open drying, Solar-cum gas-fired dryer, Longi variety, Solar tunnel drying

Introduction

Chili is an important spice and cultivated throughout the world both in open and controlled environmental conditions. Also, it is one of the most important and vital items used in our kitchens for making several spice recipes and food items (Handayani *et al*., 2022). It can be used as a powder (dried) and green (fresh) forms in making of several dishes for bringing the delicious flavor and color. Studies had been reported that the chilies have several types of vitamins and it is the best source to get the vitamin A, B, C and E. Besides, chilies contain several types of other nutritional elements (such as copper, potassium, molybdenum, thiamin, folate and manganese). It holds seven times more vitamin C compared to orange. Its consumption is also helpful for protecting our heart from several diseases (Ajay *et al*., 2012; Ahmad *et al*., 2013; Nimrothan *et al*., 2017).

As we mentioned above that the chilies can be used as powder and fresh form as a condiment for flavoring (Ensaf and Mohsen, 2016; Turhan *et al*., 1997). Therefore, studying chilies drying methods is important factor for significant dried chilies production (Toontom *et al*., 2010; Gupta *et al*., 2018). Hossain and Bala reported that the drying chilies have several benefits, such as it can be stored for long term, it can generate high revenue and it import to the overseas markets can help to stable the country economy.

A study by Gupta *et al*. (2002) had defined the process of the chilies drying. They reported that the term drying is defined as a process or method which is used to remove the amount of water present in any agriculture product. There are several types of drying method but the working principle of all drying methods is same. In all method, a warm air is continuously collision with the any water holding body. Satish *et al*. (2015) stated that drying is one of the oldest methods which is used for food preservation. Besides, it is important to decrease the moisture content of chili after harvesting from the field. Because at that time, the freshly harvested chilies are holding around 80-90% moisture content which can provide the best growing conditions for many harmful pathogens and could significantly impact on the overall quality (Kyi *et al*., 2020; Samreen and Rao, 2017). The amount of the available moisture percentage can provide suitable growth conditions and can support the microbes living inside the fruit. Thus, before storing or using the harvested chilies; the moisture reduction is necessary. In addition, during the low market prices when the chilies supply in market is abundant, at that time drying chilies can be beneficial and economical. Due to the huge amount of freshly harvested chilies available in the market, the farmers are not able to get suitable cash back. Also, drying chilies is an ideal way to save and store the abundant harvest or leftover supply for future consumption. However, both in domestic and international markets, the interest in dried chilies are increasing, and if dried chilies have good quality and are well dried, they could be sold out in higher rate. In addition, drying the agricultural product depends on several real time ground conditions. However, solar radiation, temperature and humidity are some of the most important factors need to consider during drying the chilies (Gupta, 2016). Condori *et al*. (2001) study reported that there are many methods that can be used for drying the chilies. Among several methods, the traditional drying and oven drying methods are mostly used in the world. The traditional sun drying method is dominant to all other drying methods. But it has several disadvantages and many possibilities that the final quality of dried products can be highly affected by the traditional drying method. Because there are many possibilities that it can significantly increase the microbial proliferation and superiority deterioration in chilies. Also, with open drying method there are many possibilities that dried chilies could be highly affected by the surrounding real time filed conditions (flowing dust with air, ground dirt, temperature, humidity, precipitation, livestock activities, birds and animals, rodents, and insects). Mangaraj *et al*. (2001) compared different chili drying methods and reported that under open drying condition, the overall losses could be 40–60% higher. This method is considered the simplest and cheapest method of drying different agricultural products by directly exposing the products to the sun. However, the major disadvantage of this method is that the quality of the dried chilies can significantly lower than the international recommended quality limit.

Traditional drying method requires 7-20 days to reduce the initial moisture content up to 10-15%. Besides, the drying ratio depends on the surrounding weather condition (Hossain, 2003). Also, this method is a lengthy process, and taking up to 4-10 days to bring the moisture content to 9.9 % (Oberoi *et al*., 2005). Basunia and Abe (2001) concluded that solar drying method is the environmentally friendly and economical drying method for farmers. However, most constructed solar dryers use only solar energy as a heat source for drying, which makes the solar dryer dependent on climatic conditions limiting its use in cloudy periods and at night. As a result, agricultural products harvested in the rainy season are still subjected to spoilage. A study by Manjula and

Ramachandra (2014) informed that we compared different chili drying methods and found that the chilies dried with traditional dried were significantly higher titrable acidity content than that of chilies samples dried with solar tunnel method. Besides, the chilies samples dried with solar tunnel had higher lightness, shininess, and redness parameters values compared to other methods. However, the capsaicin content of dried chili samples with the solar tunnel was more than that of the chili samples dried with traditional drying method. Based on their test results, they concluded that the solar tunnel drying method was recommended for drying the fresh chili harvested from the field for better quality production compared to the open sun drying method. In addition, solar tunnel drying method took less time for drying the chili samples till the required moisture level than that of open sun drying method. Because the average maximum and minimum temperatures of the inside of the solar tunnel dryer were significantly higher compared to open sun drying ambient temperature. Dhanore and Jibhakate (2014) reported that solar tunnel dryer is economical and environmentally friendly chili drying method and it requires 24 hours to reduce the moisture content from 75% to 5%, while a total drying time of 40 hours is required for open sun drying to get the same moisture content level.

This research aimed to evaluate the performance of the solar tunnel dryer, solar cum gas dryer, and conventional sun drying methods.

Materials and Methods

Experimental setup

The current experiment was performed at PARC-AZRC (Pakistan Agricultural Research Council-Arid Zone Research Centre), Umerkot, Sindh, Pakistan. The study was conducted in November 2022. This research used three drying methods (T1= Solar tunnel, T2= Solar-cum gas-fired dryer, and T3= Open sun drying) as experiment factors having three different intervals (1st, 2nd, and 3rd). Each interval was replicated three times, and average values were reported. In addition, fresh red chilies sorted by uniform color and size were harvested from the farmer's field and brought to the experimental site. The experiment selected chili verity was Longi, and a total of 2000 g of fresh red chili samples were collected. Before starting the drying experiment, the test-selected chilies were weighed, washed, and blanched at 80 ºC for 8 minutes and drained quickly. The chilies were then dried according to the drying treatments. The chilies were dried a bit and then turned upside down regularly. The drying was carried out for 9 hours daily, the experimental measurements were begin at 9:00 am and finished at 5:00 pm each day. Afterward, at 5:00 pm, chilies samples were taken out from all drying methods, weighed, and again placed in a dryer the following day until the moisture content reached 8–10%.

Drying methods

Solar tunnel chili dryer: For the present study, a solar tunnel chili dryer was constructed at PARC-AZRC, Umerkot. The dimensions of the solar tunnel dryer were 60 ft, width 20 ft, and height 8ft, and consisted of a hemispherical roof structure. The material used for constructing the dryer was purchased from the local market. The used materials were included GI pipe (2 and 1-inch diameter) with 30 (11 pipes) and 65 ft (5 pipes) length, 2100 ft^2 0.25 mm thick polythene sheet. Figure 1 shows the solar tunnel dryer.

Figure 1: *Solar tunnel chili dryer.*

Solar-cum gas fired chili dryer: One solar-cum gas-fired dryer system was developed for the current study at the experimental station. The developed system was mainly composed of 8 different solar radiation collector panels having lengths and widths of 7 ft and 3 ft each. The total length of the system was 56.6 ft. The solar radiation collectors were developed from the glass, absorber plate, thermo-pore layer, glass wool, and air duct system. The developed solar radiation collectors were placed on an iron stand with a rear side height of 4.2 ft, front side height of 2.2 ft, 6.56 ft, and width of 2.36 ft. One drying chamber was developed with dimensions of 7 ft, width 5, and height 5. The drying chamber consisted of an MS sheet of 16 gauge sandwiched with a glass wool layer of 25mm, MS angle, MS channel, MS flat, and MS T iron. The entire tray-holding capacity of the drying chamber was 120 trays.

Each tray's size was 2 ft and width 2 ft with 1 inch MS iron angles as the border. The base of the trays was made of stainless-steel mesh No. 4. The axial fan was installed between the solar radiation collector panels and the drying chamber to transfer the warm air toward the chamber. The axial fan specifications were 250 watts power requirement, 1400 RPM, 6 blades, and the fan's diameter was 18 inches. Furthermore, solar energy was used for running the axial fan. Therefore, three 24-volt solar PV plates, one inverter (input: 220V and output: 24V), and 2 dry batteries (12V, 100A) were used. However, the LPG gas cylinder operated the developed solar dryer on gas. Solar-cum gas fired dryer used for the present experiment is shown in Figure 2.

Figure 2: *Solar-cum gas fired dryer.*

Traditional drying method (Drying in an open environment): Sun drying is a traditional method for reducing the moisture content of several agricultural products by spreading the grains under the sun. The solar radiation heats the grains and the surrounding air and thus increases the rate of water evaporating from the grains. In this study, we used a green net and spread the chilies for drying in the open environment. The method of open sun drying is shown in Figure 3.

Figure 3: *Chilies are drying in an open environment.*

Climate data

The inside and outside temperatures and relative humidity were recorded at each interval. The temperature and relative humidity data were recorded with the help of model number HTC2, Digital LCD Temperature Humidity Meter Indoor/Outdoor Room Thermometer Clock Hygrometer with the sensor.

Measurements

Moisture content: The moisture content of the chili samples was measured each day during the experiment at 5:00 pm. The measurements were performed by using the wet basis method. Therefore, the electrical balance weighing scale was used to weigh the chilies samples were measured before and after putting them in the dryers. The moisture content calculation on a wet basis was measured by following Equation 1.

$$\text{Mw (wet basis)} = \frac{w-d}{w} * 100 \quad ...(1)$$

Where w is the wet material's weight, and d is the dry material's weight.

Estimation of aflatoxin

Estimation of aflatoxin (total) was performed by using the ELISA technique. The method was based on the "Veratox Test Method" (immunochemical analysis). For the determination of aflatoxin (total) in chilies, ten grams of representative sample was added in 50 ml of 70% methanol and the aflatoxin extraction was taken and blended for three minutes. After that the sample was filtered for extracting through Whatman No. 1 filter paper. The filtrate was taken to start the bioassay. All reagents were allowed to warm to room temperature (18-30 °C) which was present in commercially available test kit named Veratox test kit for Aflatoxin. The bioassay was completed as per direction written in the instructions of kit. The optical density in Microplate reader was read by using Microplate Manager 6 software. The Quantitative analysis was done by the VERATOX software version 3.5.1. The readings obtained up to three decimal places in ppb concentration.

Data analysis

All the recorded data was statistically analyzed to compare the difference between each method. Thus, the mean values comparisons were computed with a Statistics version 8 using the least significant difference test at a 5% level.

Results and Discussion

Three interval studies were carried out with a three different solar tunnel dryer, solar-cum gas dryer and open sun drying methods using 2000 g of red chili samples from October to November 2022. The results showed that the decreasing of the moisture content was observed with respect to time for red chili samples in all drying methods. However, the initial moisture content of fresh chili was 80% on a wet basis, and chilies were dried until the equilibrium moisture content reached 9-10%. It is evident from the data presented that chili's moisture content decreased with the increased drying time in all drying methods. The general analysis of the data showed that the T2 methods reduced the moisture content of the chili samples in minimum time compared to T1 and T3. The brief results are discussed below.

Average temperature and relative humidity

During the experiment, the average temperature (°C) and relative humidity (%) values from different test-selected drying methods were measured concerning time. The recorded data is shown in Table 1. In addition, the maximum higher average temperature was recorded from the T2 method, followed by the T1 and T3. The maximum higher average relative humidity was recorded from the T3 method, followed by the T1 and T2. The results of the average maximum and minimum temperature and average maximum and minimum relative humidity are shown in Figure 4.

Table 1: *Average temperature and relative humidity.*

Drying days	T1			T2			T3		
	Total hours	Temp	RH	Total hours	Temp	RH	Total hours	Temp	RH
Day-01	9	39	45	9	44	44	9	34	51
Day-02	18	37	52	18	40	51	18	32	58
Day-03	27	38	45	27	42	45	27	33	52
Day-04	36	41	40	36	42	45	36	33	53
Day-05	45	39	47	45	47	45	45	33	57
Day-06	54	38	47	54	48	46	54	33	55
Day-07	63	33	66	-	-	-	63	30	70
Day-08	-	-	-	-	-	-	72	32	54
Day-09	-	-	-	-	-	-	81	32	53

Figure 4 shows that while performing the experimental study of drying red chili, the minimum and maximum average air temperature of the T1 method ranged between 33°C to 41°C. However, the minimum and maximum average air temperature of the T1 method ranged between 44 °C to 48 °C. The minimum and maximum average air temperature of about 30 °C to 34°C was measured from the T3 method. In addition, the minimum and maximum average relative humidity of the T1 method ranged from 40 to 66. However, the minimum and maximum average relative humidity of the T2 method ranged from 44 to 51. The minimum and maximum average relative humidity of 51 to 70 was measured from the T3 method. The recorded average temperature and relative humidity values from T1 and T3 methods were minimal compared to the T3, which is a significant sign of both methods success. Because a study by Nimrotham *et al.* (2017) reported that in open-based drying systems, it is many possibilities that nighttime air temperature and relative humidity values could decrease and increase. However, in some cases, dried chili can absorb moisture from the air until the moisture of the dried chili is balanced with relative humidity in the air. Arundel *et al.* (1986) have reported that the relative humidity level in the air can affect the growth of fungi. It was found that the fungi in the air grew well at relative humidity higher than 60% RH. The fungi and bacteria cannot grow when the humidity is in the range of 40-60% RH. Therefore, the relative humidity must be kept in this range for food to be safe from fungi.

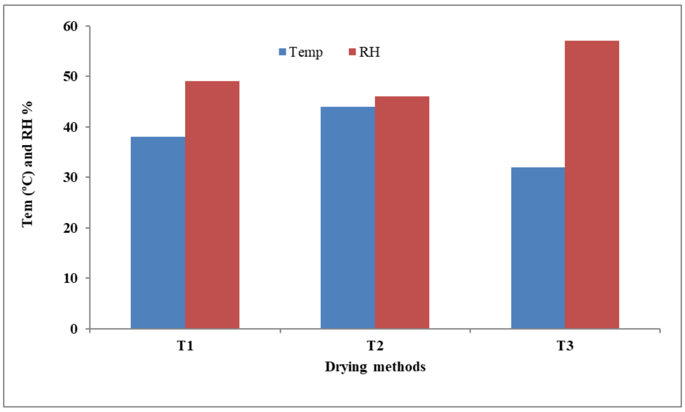

Figure 4: *Average temperature and relative humidity values recorded from different drying methods.*

Moisture content (MC) of the dried samples

The results of the decrease in moisture content level of the red chilies samples concerning time in different drying methods are displayed in Figure 5. The results in Figure 5 showed that the T2 method significantly reduced the moisture content level of the red chilies samples within a short time compared to T1 and T2 methods. Jointly, the T1, T2, and T3 methods reduce the moisture content of red chili from 80% (w.b) to about 10-12% (w.b) in 63, 54, and 81 hrs, respectively. By comparing the T1 method with T2, the T1 reduced the moisture content of red chili from 80% (w.b) to about 10-12% (w.b) in 63 hrs. Besides, the T1 reduces the moisture content to the same level in 54 hrs. The main reason behind this was the average value of each drying system's air temperature and relative humidity.

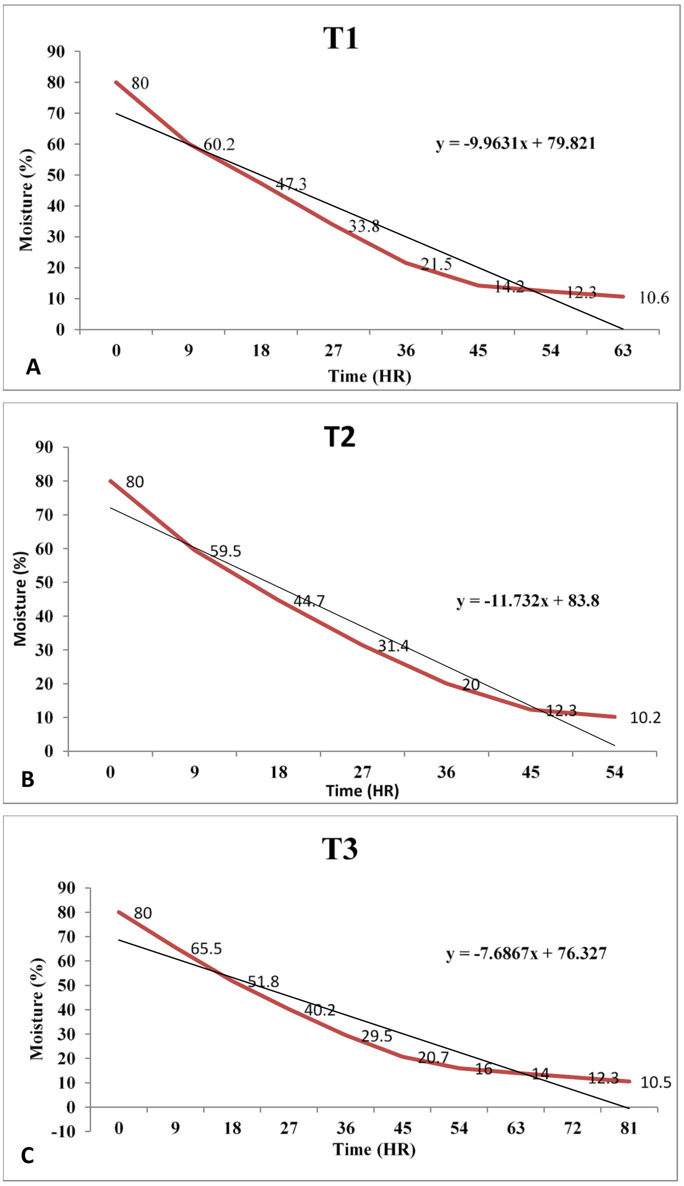

Figure 5: *Chilies moisture content reduction with different drying methods concerning time.*

Aflatoxin content of the dried red chilli samples

The result of the measured aflatoxin content is shown in Table 2. The measured total aflatoxin content of the dried samples was 3.0, 1.45, and 2.7 ppb of T1, T2, and T3 methods, respectively. The measured total aflatoxin content values were below the maximum limit recommended by CODEX. Besides, the European Union has limited the total aflatoxin content to 10 ppb per sample (Commission Regulation, 2006). These findings were agreement with the results presented by Manjula and Ramachandra (2014). They reported that the chili samples dried with solar tunnel-dried had lower aflatoxin content values compared to open sun drying method.

Table 2: *Total aflatoxin content of the dried chili samples with different drying methods.*

No	Dried sample	Total aflatoxin content (ppb)
1	T1	3.0
2	T2	1.45
3	T3	2.7

Conclusions and Recommendations

In this study, we compared three different chili drying method. Based on the experiment results, the following conclusions were made. The red chili dried in T1 and T2 from an initial moisture content of 80% to a final moisture content of 12-13 % in 63 and 54 hours, respectively, compared to 81 hours in T3. Moreover, the T1 and T2 saved 18 and 27 hours compared to the T3 method. Based on the experiment result, it was concluded that the T2 and T2 drying methods are better alternatives for T3 method and ensure product quality. These methods are not subjected to the weather conditions like the rainy season. Compared to T3, the T1 and T2 methods are best suited and recommended for drying the several agricultural products. Also, these dryers are suitable for slight and medium-scale drying of agricultural/ industrial products.

Acknowledgement

Authors are highly thankful to Pakistan Agricultural Research Council, Agricultural Linkages Programme (ALP- AE45) for providing funds during conducting the research work.

Novelty Statement

Umerkot district is the major chili producing in Pakistan and first time three different drying methods are introduced.

Author's Contribution

Behari Lal Meghwar: Project In-charge and conducted the research trail.
Attaullah Khan: Supervised the trail.
Imran Ali Lakhiar: Technical assistance at every step for write up.
Asif Ali Mirani: Proof reading and final editing.
Muhammad Siddique Daper: Co-supervised the trail.

Muhammad Waseem Kalroo: Helped in al field and Lab work.

Conflict of interest

The authors have declared no conflict of interest.

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