J Bangladesh Agril Univ 20(3): 267–279, 2022 https://doi.org/10.5455/JBAU.102921

ISSN 1810-3030 (Print) 2408-8684 (Online)

Journal of Bangladesh Agricultural University

Journal home page: http://baures.bau.edu.bd/jbau

Research Article

Evaluation of Solar Tunnel Dryer for Drying of Cabbage

Tanjima Akter, Tafura Hoque Sharna, Chayan Kumer Saha✉ and Md. Monjurul Alam

Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh-2202

ARTICLE INFO

Article history
Received: 17 March 2022
Accepted: 07 September 2022
Published: 30 September 2022

Keywords
Cabbage,
Solar tunnel dryer,
Drying,
Post-harvest loss

Correspondence
Chayan Kumer Saha
✉: cksaha@bau.edu.bd

OPEN ACCESS

ABSTRACT

Drying is an effective means of reducing moisture content of perishable fruit and vegetables to a safe storage level and reducing post-harvest loss. This study was conducted to evaluate a solar tunnel dryer for drying cabbage in comparison to traditional open sun drying at the advanced drying lab of the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. Salt pre-treated cabbage was used for drying inside the dryer and open sun drying. The parameters like solar radiation, temperature, relative humidity, and moisture content were measured using standard instruments during the experiments. The results showed that the maximum peak temperature inside the drying chamber was 45 °C during mid-day (12 pm) when solar radiation was 600 w/m^2 and an average inside temperature was approximately 30 °C to 40 °C in a full sunny day (9:00 AM to 04:00 PM) when average solar radiation was 321±115 W/m^2. The moisture content of sliced cabbage reduced initially from 94.42, 90.18, and 92.24 % (w.b.) to 4.85, 15.84, and 15.71% (w.b.), respectively, and drying time of the dryer was 28, 21, and 19 hours in 1st, 2nd, and 3rd trials, respectively. The drying rate and drying efficiency were found 0.15 kg/hr and 8.22 %, respectively in tunnel dryer and 0.02 kg/hr and 3.38 %, respectively in open sun drying. The color and texture of the solar-tunnel-dried cabbage were better than obtained from the open sun drying method. Further experiments are required for estimating drying capacity with the operating cost of the solar tunnel dryer when the dryer will be used with its full capacity.

Introduction

Agriculture is the largest employment section and main source of livelihood in Bangladesh. Bangladesh is the 3rd largest producer of vegetables (FAO, 2019). Many varieties of vegetables such as cabbage, tomato cucumber, potato, pea, bean, etc. are produced here. Vegetables are the fundamental commodities for human's daily life and the main sources of nutrition, vitamins such as vitamins-A, C, thiamin, and minerals such as calcium and iron. The annual demand for vegetables in Bangladesh is about 13.25 million tons whereas the production is only 3.73 million tons (Rahman et al., 2021) which showed a vast amount of production shortage to supply. In Bangladesh, the average per capita daily vegetables intake is 56g/day, where the recommended intake is 250g/day (FAO, 2017) which is very low compared to other countries. From 2004 to 2019, vegetable production increased from about 2 million to 6.3 million tons. Simultaneously, the area used for vegetable production increased from about 333 thousand to 651 thousand hectares, implying a slower growth in land used for vegetable production than the growth in production itself (Pamuk et al., 2021).

Cabbage or *bandha kopi* is a popular winter vegetable. In Bangladesh, this vegetable is grown in about 9,688 ha; the total production of cabbage comes approximately at 90,795 million ton (Banglapedia, 2021). The post-harvest losses of vegetables are in the range of 20 to 40% (Hassan, 2010). The post-harvest losses of cabbage are 26-27%, due to improper handling and lack of storage facilities (Gonzales and Acedo, 2016). The post-harvest loss can be reduced by controlling the moisture content of the product by the drying method. For storage purposes, the moisture content of cabbage should be reduced to 7 to 8% (w.b.) to make it available on food tables in other seasons.

Drying is the traditional method of preserving fruits, vegetables, fish, meat, etc. and it helps to keep product longer period and can be used in offseason. Leon et al., (2002) found that there were many types of solar dryers exist such as active dryer, passive dryer, mixed-mode dryer, box-type dryer, cabinet dryer, and tunnel dryer.

Cite This Article
Akter, T., Sharna, T.H., Saha, C.K. and Alam, M.M. 2022. Evaluation of Solar Tunnel Dryer for Drying of Cabbage. *Journal of Bangladesh Agricultural University*, 20(3): 267–279. https://doi.org/10.5455/JBAU.102921

Three different types of solar dryer which is based on natural convection solar dryer of potato, chilies, and mushrooms were reported (Sharma et al., 1995). Natural convection solar dryers with heat storage for drying leafy vegetables and other agricultural products were investigated in Cameroon (Berinyuy et al., 2012). The overall dryer efficiency was 17.68 %, drying time reduction between 30 % and 50 %, moisture extraction efficiency of 79.15 %, and airflow of 9.68 m^3/hr. The quality of the final product is acceptable in taste and appearance and farmers could able to uptake price within 2 years payback period. Bala & Woods (1995) also presented a technique for optimization of the natural-convention solar dryer where three energy balance equations were used on the cover, absorber, and the air inside the collector. It was found that grain capacity has a relatively greater influence on drier design, giving rise to a longer collector which causes greater buoyancy at greater grain depth. Bala et al. (2003) conducted a study on solar tunnel dryer for drying pineapple and found drying rate and the temperature in the drier had risen in the ranges of 34.1–64.0°C for a change in solar radiation from 0 to 580 W/m^2 using some efficient equations. The proximate analysis also indicates that the pineapple dried in the solar tunnel drier is a good quality dried product for human consumption. Parvin et al. (2021) used a solar conduction dryer for drying fruit and different vegetables and found that air temperature was 1 to 14^{o}C higher than the ambient air temperature and had a drying efficiency of 6.04% to 19.8%.

On the other hand, the traditional open sun drying method is very familiar which is the cheap and very easy method but poor dried quality. So, the solar drying method would be a better option to produce quality dried products than open sun drying. Despite plenty of production, the cabbage is not obtainable all the time to fulfill our nutritional value. Fresh cabbage contains up to 90-94% of water and it is needed to dry with an appropriate drying method which will remain useable for a long time for all-purpose.

Hohenheim type solar tunnel dryer was used before successfully for drying fruits, vegetables, spices, medicinal plants, and fish (Bala and Debnath, 2012). They dried different types of vegetables like mushrooms, Chilli, etc., but did not conduct any experiment for cabbage using a solar tunnel dryer. Hence, this study was conducted to understand the spatial temperature and moisture content distribution in and outside solar tunnel dryer, and to investigate the technical performance of solar tunnel dryer for drying cabbage.

Materials and Methods

Solar Tunnel Dryer

The Solar Tunnel Dryer consists of an air inlet, collector unit, drying chamber, air outlet, solar module, plastic net, wooden base support structure, roof structure for supporting the plastic cover, and DC fans. Both the collector and drying are covered with a transparent plastic sheet and attached with a rubber belt in the frame (Figure 1). The use of plastic cover can be able to save the product from rain, excess airflow, dust, and insects. Black paint is used in the dryer bed which is made of wood and a wooden frame split net tray is placed just above the drying chamber of the solar tunnel dryer. The system is placed horizontally and airflow rate is provided by three DC fans which are operated by one photovoltaic module (50 W).

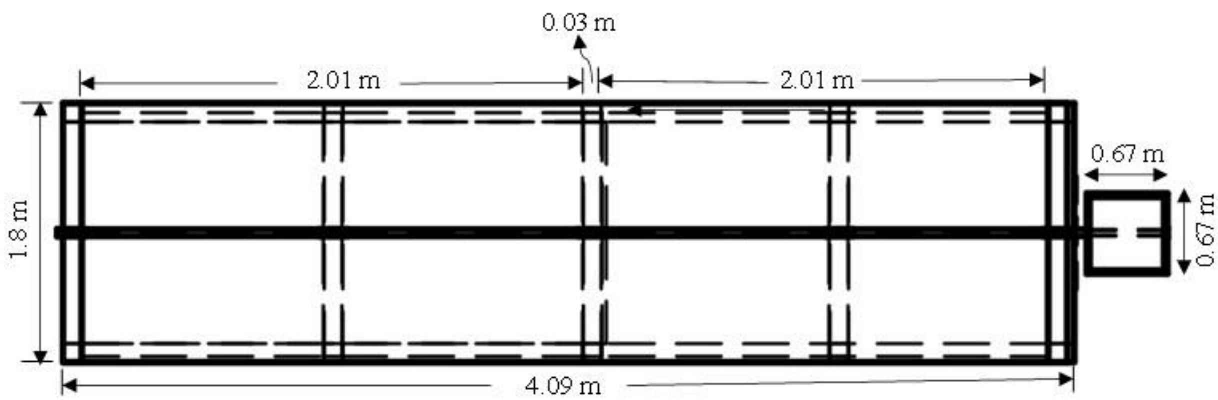
Figure 1. Solar Tunnel Dryer

The drying unit is the main part of the dryer whose surface area is 4.18 m^2. The size of the different components of the solar tunnel dryer is given in (Table 1). The three-dimensional view with dimensions is shown in figure 2. The mechanism of the solar tunnel dryer is given in figure 3 and assumed a unidirectional airflow. The solar radiation falling through the transparent cover in both the collector and drying units then heats the air entering the collector unit through convective heat transfer at the cover and the absorber plate. This enhances the drying rate and the temperature in the dryer rises in the ranges of 35.1^{0}C to 52.2^{0}C (Bala and Mondol, 2001). The section of the dryer can be extended up to 8.18 m for more capacity of drying.

Table 1. Determination of the dryer dimensions

Dryer parts	Length, m	Width, m	Height, m	Surface area, m^2
Drying unit	2.01	1.80	0.61	3.62
Drying tray	1.96	1.75	0.13	3.43
Collector unit	2.01	1.80	0.61	3.62
Solar module	0.67	0.67	1.60	0.45

(a)



(b)

Figure 2. Solar Tunnel Dryer 3-D Design View, (a) Top view and (b) Top view with dimensions in mm

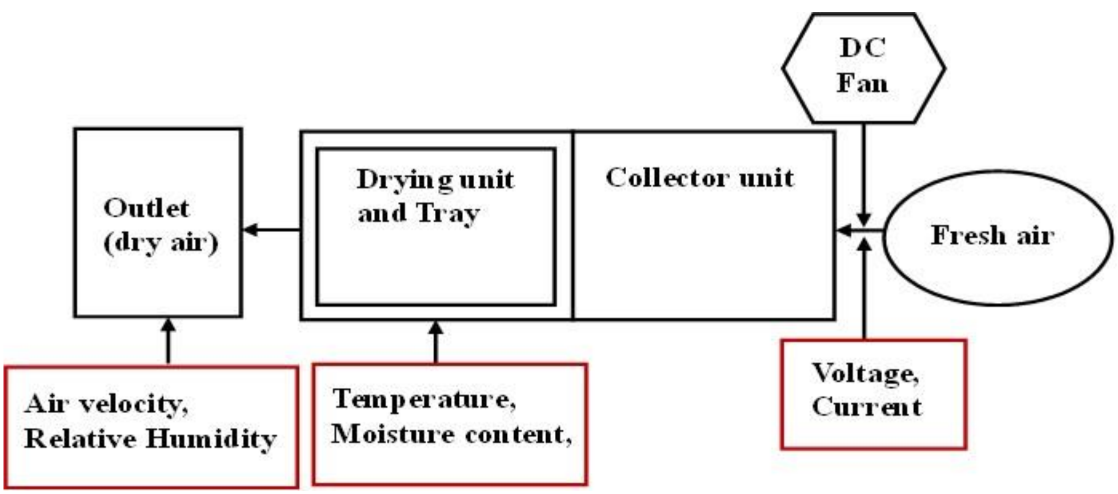


Figure 3. Flow chart of Solar Dryer System

Experimental site and time

An experiment was conducted during February 2020 at the Advance Drying Lab at Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh.

Design and Set-up of the dryer

The frame of the dryer was made of metal. The tray made by net was constructed in the upper portion of the base (Figure 4a). Three DC fans are attached with the mainframe by wood and one solar was fixed in the north and south direction (Figure 4b). The axis of the solar tunnel dryer is east-west direction so that maximum exposure of southern radiation can be obtained. The metallic frame structure of the tunnel dryer was covered with a transparent polyethylene sheet of at least 200-micron thickness (Figure 4c).

Sample preparation

Selection of Experiment Sample

Cabbage (variety: BARI Bandha Kopi-2) was selected for the drying experiment as it was available in February 2020. About 4 to 5 kg of cabbage was used for the experiment in each trial. The cabbage was purchased from the K.R market of BAU.

(a) (b) (c)

Figure 4. Different Parts of Dryer Construction (a) Preparation of tray, (b) Fan setting on Dryer, (c) set-up of plastic sheet

Preparation of Cabbage

The cabbage was washed with water (Figure 5a) and then chopped into a thin slice about 5 to 6 mm in size using a very sharp knife (Figure 5b). The optimum size is necessary for drying properly.

Pre-treatment

Pre-treatment was done by salt after chopping (Figure 5c). To prepare the solution, 5% salt was mixed with water for 30 minutes pre-treatment. The moisture content was found 94% after pre-treatment. It helps to protect the product from fungus and bacteria in long-time storage, reduces the drying time, and reduces the initial moisture content before drying.

(a) (b) (c)

Figure 5. Different Steps of Sample Preparation (a) Fresh cabbage, (b) Chopping cabbage, and (c) Pre-treatment with salt solution

Sample Set-up and experimental procedure

Cabbage was put in the dryer at three vertical lines named as S_1, S_2, and S_3 at same intervals (Figure 6) and open sun drying. Sliced cabbage was placed uniformly so that every slice dries properly through hot air coming from the heat collector unit. For the drying experiments, determine the initial moisture content using the standard oven-dry method (OVM) and others parameters was measured after 1-hour interval. The processed cabbage was placed inside the dryer. After finishing the trial, the cabbage was packed in 50-micron thickness airtight poly bag for long-term storage. On the other hand, the same procedure was followed for the open sun drying method.

Drying Parameter Measurement and Instrumentations

The k-type thermocouples connected with a Fluke data logger (Range- ±0.018%; Made in the U.S.A) were used for measuring the inside and outside temperature of the dryer. Four thermocouples were placed at the middle of the dryer at $T_{1\,(collector)}$, T_2, T_3, and T_4 locations. Two thermocouples were placed on the south side of the drying section at T_5 and T_7. One thermocouple was placed on the north side of the drying section at the T_6 location. Finally, one thermocouple was placed outside of the dryer for measuring ambient temperature. All thermocouples were connected to the data logger with a computer for real-time temperature recording in 1-hour intervals (Figure 7). A solar meter (range 0 to 1250 W/m^2, made in Taiwan) was used to measure Solar Power. A precision handheld Relative humidity (Humidity range: 0% to 100%, 9V battery) meter was used to measure relative humidity. Anemometer (Made in Taiwan, Model-RS 212-578,) Meter range: Km/h=3.6-72.0) is a device for measuring air velocity. The DC fans (12V-DC; 1000 mA; 12 W; Made in Germany) at the required flow rate are provided by an electric-operated fan or a fan driven by one photovoltaic module. Photovoltaic solar panels (Model-KC50; Nominal Maximum Output Voltage-16.7V; Manufacturer by Made in Japan) absorb sunlight as a source of energy. Voltmeter (Made in England) was used for measuring voltage. Oven (made in Korea) was used for measuring dry matter of samples and finding out moisture content by using the oven-dry method. An electric balance (range- Max./d: 320g/0.001g; Made in Japan) was used to measure the accurate weight of samples. An electric weighing scale was used for weighing the initial and final weight of the sample before and after drying.

Figure 6. Cabbage are placed upon on the dryer trays

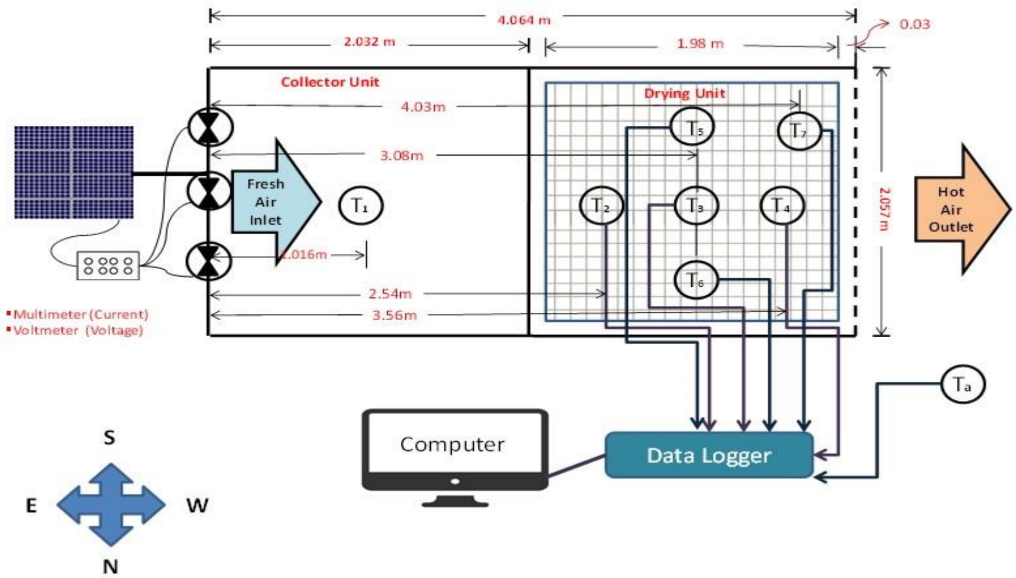


Figure 7. Schematic Diagram and Mechanism and Sensor Placement of Solar Tunnel Dryer

Calculation of Drying Technical Parameters

Moisture Content

The moisture content of wet basis is the ratio of the weight of water at a given time compared to total weight at that time. The required sample was weighed and placed in the oven for the dry product at 24 hours at 105^{0}C. The wet basis method was taken into consideration. The moisture content is calculated using equation (1):

$$MC_{wb} = \frac{W_w}{W_w + W_{dm}} \times 100 \quad .... (1)$$

where, MC_{wb} = moisture content (w.b.), %
W_w = weight of water removed, g
W_{dm} = weight of dry matter, g

Amount of Moisture removed

The amount of moisture removed from the sample was determined by the following equation, (Hossain et al., 2018).

Amount of moisture removed,

$$M_r = \frac{W_i[(M]_i - M_f)}{(100 - M_f)} \quad .... (2)$$

where,
M_r= Mass of water removed from wet samples, kg
W_i= Initial mass of the samples to be dried, kg
M_i=Initial moisture content (w.b.) of samples, %
M_f= Final moisture content (w.b.) of samples, %

Drying Rate

The drying rate is the ratio of the mass of water removed from wet samples to total drying time. The drying rate can be calculated by equation (3),

$$Drying\ rate = \frac{\mathbf{Mr}}{T} \quad .... (3)$$

where,
Mr = mass of water removed, kg
T = drying time, hr

Energy consumption

The total energy consumption of the solar tunnel dryer was measured from the solar radiation, the drying area and drying time of the solar tunnel dryer. The total energy consumption was calculated with the equation (4):

$$E_t = \frac{R_s A t}{10^6} \quad .... (4)$$

where,
E_t = energy consumption, MJ
R_s = solar radiation, W/m^2
A = drying area of solar tunnel dryer, m^2
t = drying time, s

Drying Efficiency

Drying efficiency can be calculated by using equation (5). For solar tunnel dryers, the drying efficiency is given by,

$$\eta = \frac{M_r L}{E_t} \quad .... (5)$$

where,
η = drying efficiency, %
M_r= weight of water evaporated, kg
L = latent heat of evaporation of water (2.5 MJ/kg), MJ/kg
E_t =total energy consumption, MJ

Results and Discussion

Variation of solar radiation and voltage of solar tunnel dryer

During drying of cabbage, the variation of solar radiation and voltage were observed (Figure 8). The voltage was increased with the increases of solar radiation. From all three trials, the same scenario was seen where the solar radiation varied from 0 to 600 W/m^2 while the generated voltage varied from 0 to 16 V. The maximum solar radiation was found 600 W/m^2 and found on the 3rd day of 3rd trial at 12.00 pm when the highest voltage was 16 V. Bala et al. (2003) examined that the variation of solar radiation and voltage was 0 to 580 W/m^2 and 0 to 14 V. During the experiment, it was found that the solar radiation varied from 0 to 511 W/m^2 in 1st trial, 0 to 520 W/m^2 in 2nd trial, and 0 to 600 W/m^2 in 3rd trial.

Temperature distributions in and outside of the solar tunnel dryer

The variation of temperature distributions, the temperature of ambient, collector temperature, and drying unit temperature are shown as in figure 9. The drying process was carried out from morning 9.00 AM to evening 4.00 PM for 1st, 2nd, and 3rd trials. The figure shows that the inside temperature of the drying unit was higher than the ambient temperature of the air in three trials.

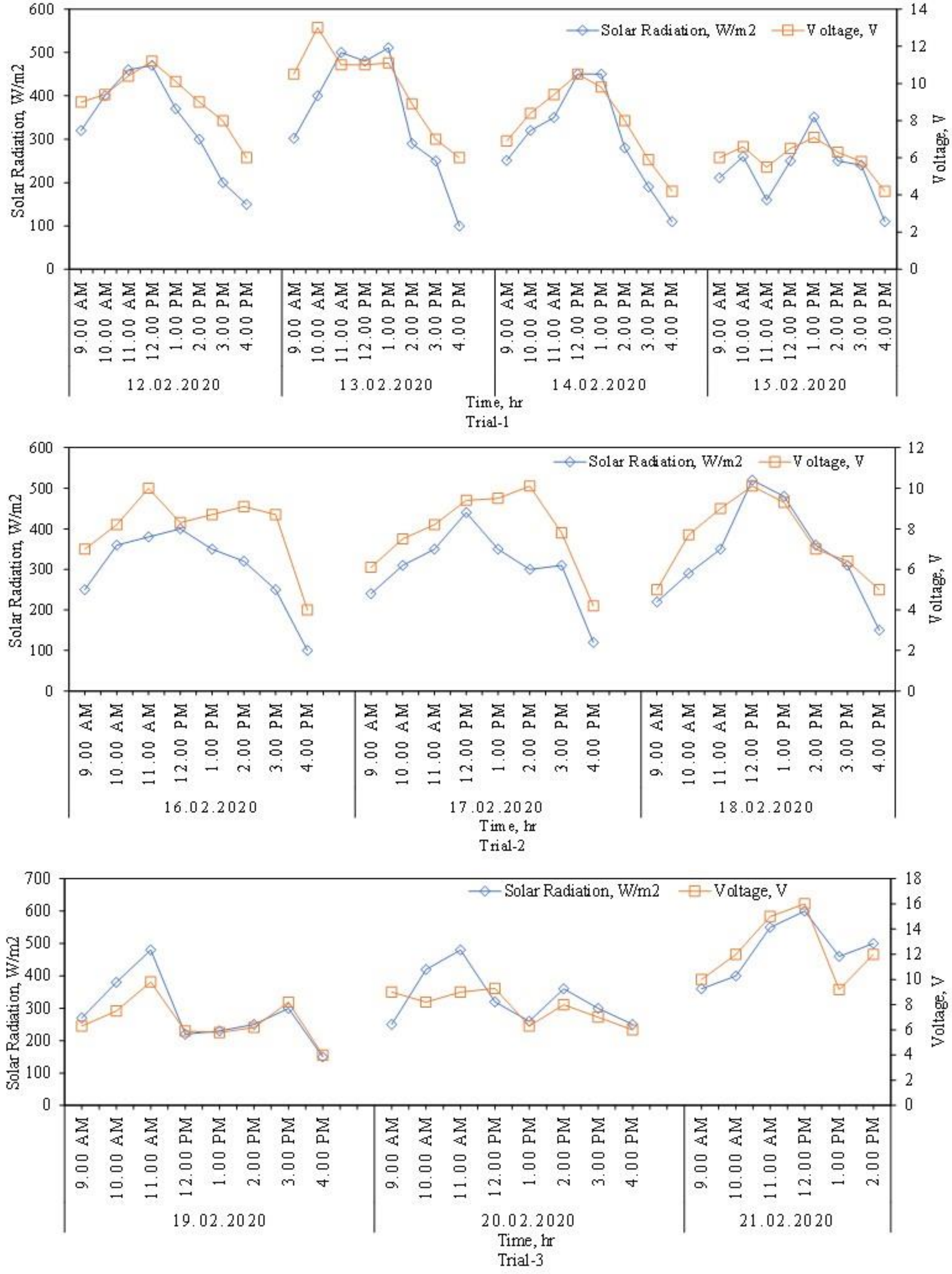


Figure 8. Variation of Solar Radiation and Voltage of the solar tunnel dryer in Trial 1, Trial 2, and Trial 3

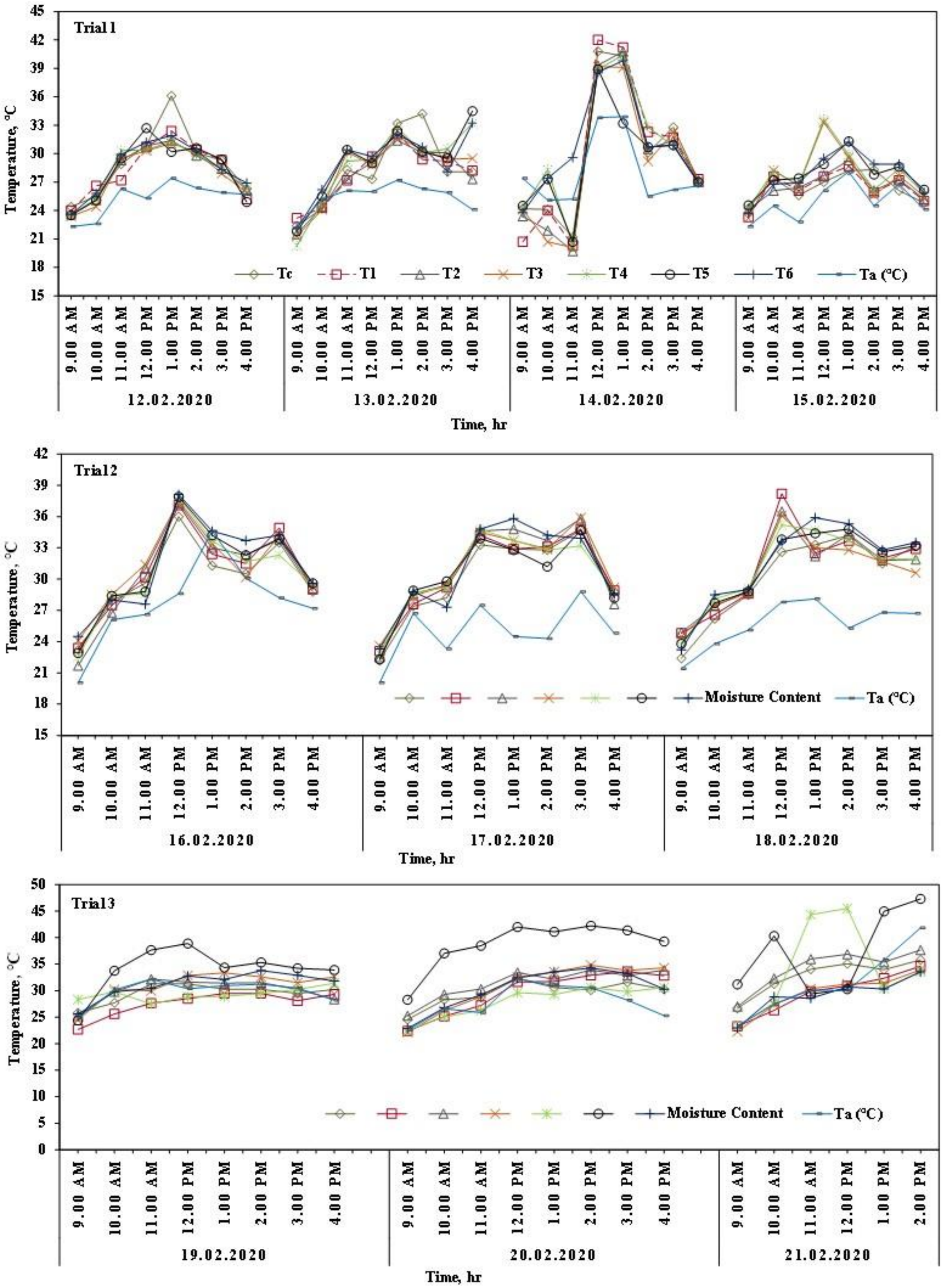


Figure 9. Variation of temperature distributions in and outside of the solar tunnel dryer in Trial 1, Trial 2, and Trial 3 where T_1= Collector temperature, T_2= Tray inlet temperature, T_3= Tray center temperature, T_4= Tray outlet temperature, T_5= Tray center-left temperature, T_6=Tray center-right temperature, T_7 = Tray outlet-left temperature, and T_a = Ambient temperature

The temperature inside the dryer was optimum for drying pre-treated cabbage. The Higher temperature is not good for some food products (Vega-Gálvez et al., 2008) and Turhan et al. (1997) suggested that using temperature above 70 ⁰C for drying results in a dark brown color due to non-enzymatic browning reaction for the red pepper.

From the experiments, the peak ambient air temperature was found 33.80, 28.80, and 35.76⁰C according to 1st to 3rd trials. The ambient air temperature was 27.40, 27.20, 33.80, and 28.10⁰C in found 1st to 4th day of 1st trial, and 28.60, 28.80, and 27.80⁰C in found 1st to 3rd day of 2nd trial and 30.34, 30.55, and 35.76⁰C in found 1st to 3rd day of 3rd trial. The collector air temperature raised maximum of 40.80⁰C in whole experiment.

According to Janjai and Keawprasert (2006), the range of temperature helps accelerate the vaporization of water in the jackfruits without any damage to this product and the ambient temperature rise at the outlet of the collector was 10°C to 25°C and the peak temperatures of the outlet air was in the range of 50°C to 60°C for most cases, depending on weather conditions. It was noticed that among all the three trials for the 1st trial the drying time was 4 days, and both 2nd and 3rd trials the drying time were 3 days. The maximum average temperature was found 39.67℃ when the ambient temperature was found 33.80℃ and the minimum drying temperature was 21.70⁰C, at the same time ambient temperature was 22.20 ⁰C on the 3rd day of 1st trial. The sunlight was moderate the rest of the day of 1st trial, for this reason, the average temperature of 1st day was found 32.06℃, 2nd day was found 32.34℃ and 4th day was found 29.74℃. On 1st day of 2nd trial at 12.00 pm, the maximum average drying temperature was found at 37.39℃ when the ambient temperature was found 28.60℃. According to the 2nd and 3rd day of the 2nd trial, the maximum average temperature was found at 34.71 ℃ and 35.14 ℃. The maximum average drying temperature was found at 36.63℃ when the ambient temperature was found at 33.86℃ at 2:00 pm on the 3rd day of the 3rd trial.

According to the 1st and 2nd day of the 3rd trial, the maximum average temperature was found 32.10℃ and 34.11℃. As a result, 1st trial takes the highest time to compare to the other two trials, which were 28 hours, 21 hours, and 19 hours. The temperature was fluctuated for weather conditions and for this reason temperature variation occurred in every trial we also found the variation of temperature was 5-12℃ higher than the ambient temperature which was recorded inside the dryer.

Variation of moisture content in a solar tunnel drying and open sun drying

A comparison of the moisture contents of cabbage in the solar tunnel drier and the traditional open sun drying method for a typical experimental run during drying is shown in figure 10. The moisture content of salt pre-treatment cabbage of a typical trial run was reduced 94.42 % to 3.62 % (w.b.) in the S_1 sample location of the tray, 5.04 % (w.b.) in the S_2 sample location of the tray, and 5.88 % (w.b.) in S_3 sample location of tray in 28 hours of drying while it took 28 hours of drying to bring the open sun drying moisture content 8.82 % (w.b.) of 1st trial. In the 2nd trial of the experiment in 21 hours moisture content was reduced 90.18 % to 15.47 % (w.b.) in the S_1 sample location of the tray, 16.29 % (w.b.) in the S_2 sample location of the tray, and 15.75 % (w.b.) in S_3 sample location of tray whereas it took the same time to bring the open sun drying moisture content 18.53 % (w.b.). In the 3rd trial of the experiment in 19 hours moisture content was reduced 92.24 % to 14.41 % (w.b.) in the S_1 sample location of the tray, 18.30 % (w.b.) in the S_2 sample location of the tray, and 14.43 % (w.b.) in S_3 sample location of tray whereas the open sun drying method need the same time to reduce moisture content 17.74 % (w.b.). The drying time was taken the same for both solar tunnel dryer and open sun drying but there is a variation of moisture content.

Tomar et al. (2017) experimented in natural convection solar tunnel dryer for mango that it took 9.5 hours to dry mango slices from a moisture content of 85.5% wet basis to a final safe moisture content of 13.0% wet basis. Whereas solar tunnel dryer needs 7 hours to reduced moisture content 94% (w.b.) to 10% (w.b.) and reported that the faster drying of pineapple slices inside the solar tunnel drier is since the pineapple in the drier received energy both from the collector and from incident solar radiation, while the control samples received energy only from incident radiation and lost a significant amount of energy to the environment.

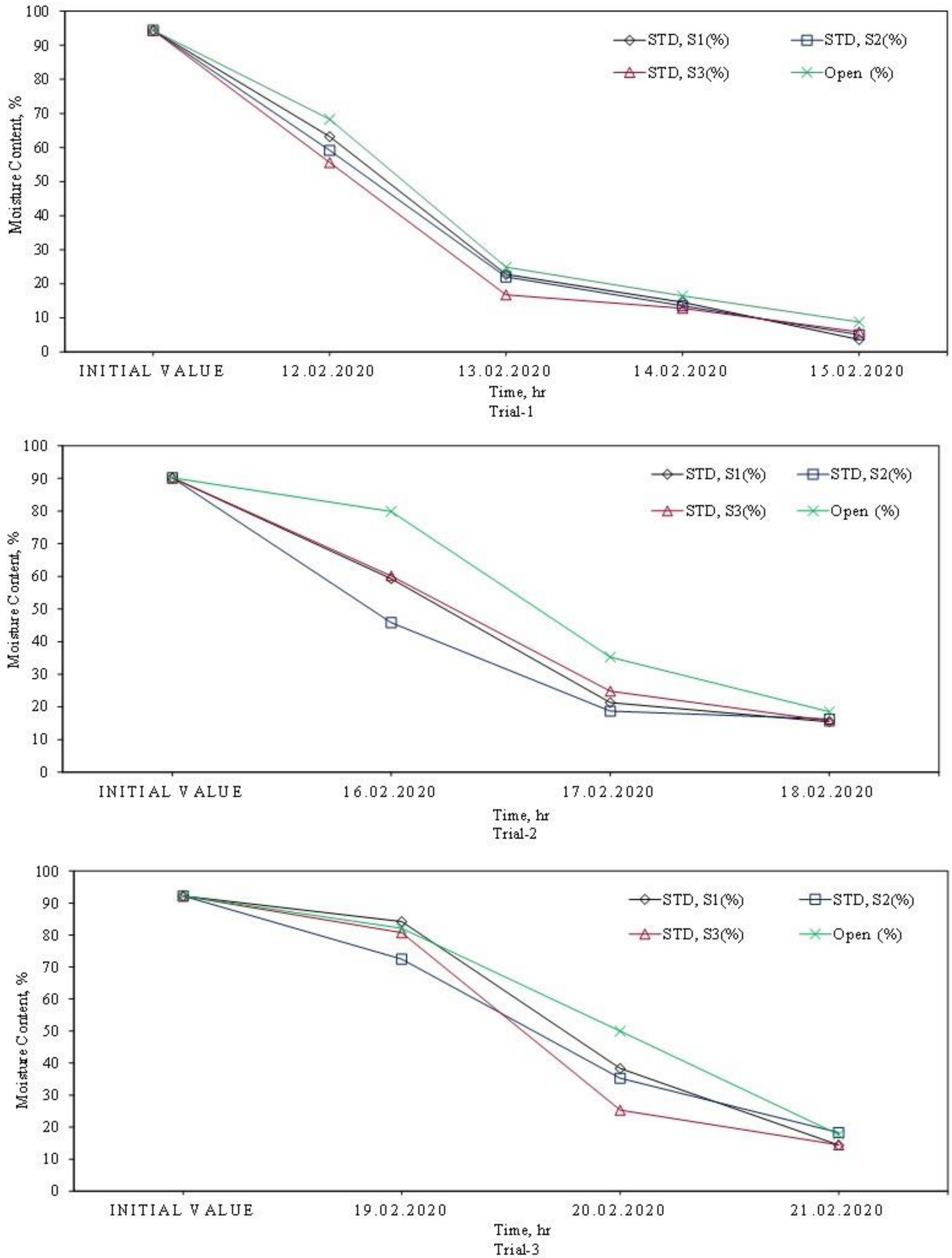


Figure 10. Variation of moisture content with time in a solar Tunnel drying and open sun drying in Trial 1, Trial 2, and Trial 3 where STD-S_1= Solar tunnel dryer tray-right moisture, STD-S_2= Solar tunnel dryer tray-center moisture, STD-S_3= Solar tunnel dryer tray-left moisture, and Open= Open sun drying moisture.

Technical Performance of Solar Tunnel Dryer and Open Sun Drying Method

The temperature variation inside and outside of STD and ambient temperature were shown in Table 2. The inside temperature of the solar tunnel dryer (STD) was 5-6 ℃ more than ambient temperature. In STD, the maximum mean ± SD temperature was found in the 2nd trial, and the minimum was found in the 1st trial. On the other hand, about ambient temperature, the maximum mean ± SD temperature was found 3rd trial.

The technical performance of the solar tunnel dryer (STD) and open sun drying (OSD) was shown in Table 3. The moisture removal rate of solar tunnel drying over sun drying was 3-4 % more and the drying rate and drying efficiency of the tunnel dryer was higher than the open sun drying method in all trials. For STD, the average drying rate was 3.59 (%MC/hr.) and for OSD the average drying rate was 3.47 (%MC/hr.). The drying efficiency of STD and OSD was 8.22 % and 3.38 % respectively.

Table 2. Temperature variation inside and outside of STD and ambient temperature

Trial No.	Solar Tunnel Dryer (STD)			Ambient Temperature,		
	Maximum Temperature, ^{0}C	Minimum Temperature, ^{0}C	Mean ± SD	Maximum Temperature, ^{0}C	Minimum Temperature, ^{0}C	Mean ± SD
1	39.67	21.70	28.43±1.36	33.90	22.20	25.87±2.62
2	37.39	22.84	30.76±0.87	34.60	20.06	26.10±3.20
3	36.63	24.00	31.21±4.31	35.76	22.55	29.14±3.35

Table 3. Technical Performance of STD and OSD

Trial No.	Pre-treatment Sample	Initial MC, MI (%)	Final MC, Mf (%)	Initial Weight, Wi (kg)	Final Weight, W_f (kg)	Solar Radiation (W/m^2)	Drying area, A (m^2)	Drying Time, T (hr)	Moisture removed M_r (kg)	Drying Rate (kg/hr)	Energy consumption, Et (MJ)	Drying Efficiency, η (%)
1	STD	94.42	4.85	3.73	0.22	304.25	3.43	28	3.51	0.13	105.19	8.34
	Open sun	94.42	8.82	0.40	0.03	304.25		28	0.38	0.01		
2	STD	90.18	15.84	3.63	0.24	312.92	3.43	21	3.21	0.15	81.14	9.88
	Open sun	90.18	18.53	0.28	0.02	312.92		21	0.25	0.01		
3	STD	92.24	15.71	3.72	0.21	354.09	3.43	19	3.38	0.18	83.07	10.16
	Open sun	92.24	17.64	0.48	0.03	354.09		19	0.43	0.02		

The efficiency was more in solar tunnel dryer because the hot air trapped inside the dryer and the fan acted like a blower that the hot air was passing through the product in full trial time. Whereas in the open sun drying method the process was continued by only sunlight.

Dried cabbage Using Solar Tunnel Dryer

Some samples are shown hereafter finishing the Solar Tunnel Drying trial (Figure 11). Visual inspection of the dried samples showed that the color and texture of solar tunnel dried cabbage were better than the open sun drying method.

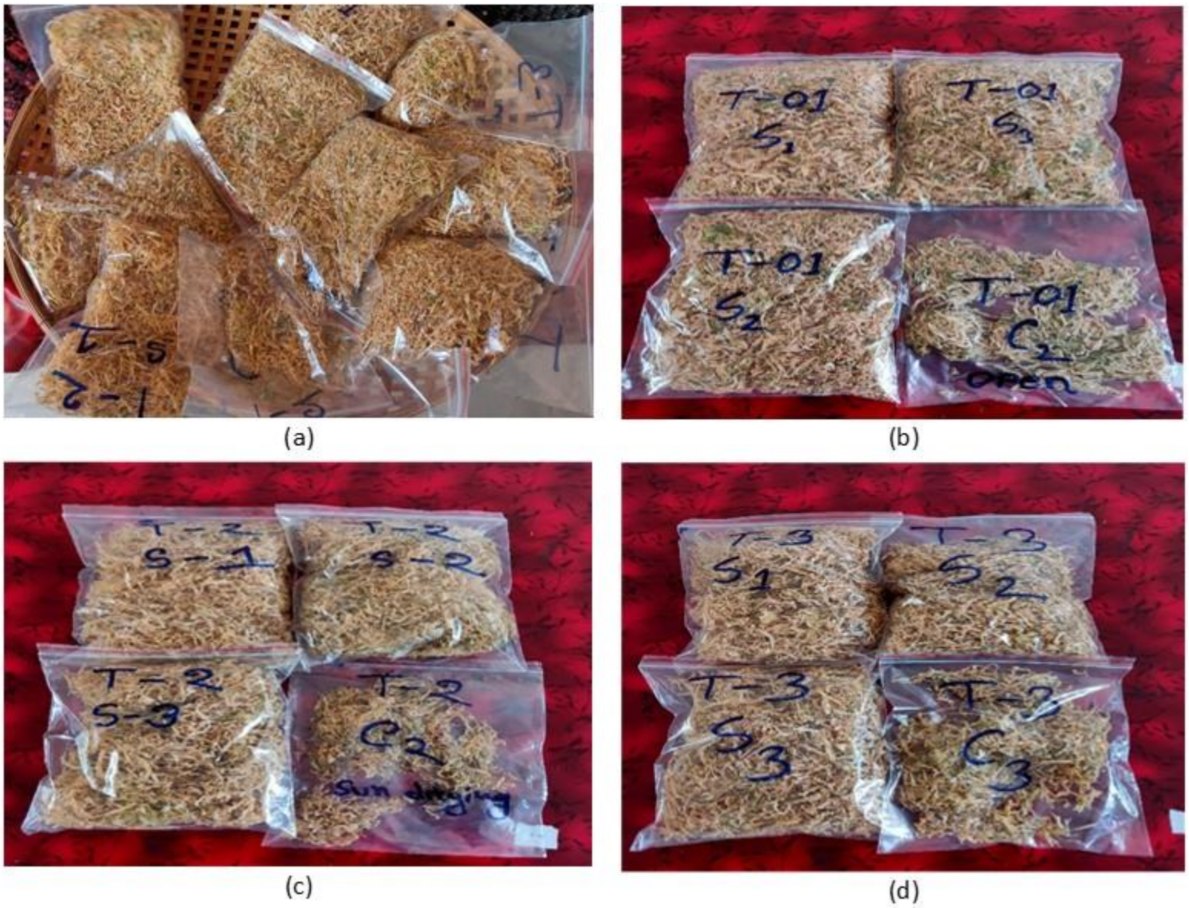


Figure 11. Dried cabbage using Solar Tunnel Dryer (STD) and Open Sun Drying (OSD) Method, (a) Dried cabbage (b) Dried cabbage of STD and OSD in 1st trial (c) Dried cabbage of STD and OSD in 2nd trial (d) Dried cabbage of STD and OSD in 3rd trial

Conclusion

The performance study of the solar tunnel dryer was conducted under meteorological conditions of Bangladesh. During the drying operation, the temperature difference between inside and outside of the dryer was low in the morning (2-3°C) and afternoon (3-4°C) as compared to midday periods (5-6°C). In 1st trial, it took 28 hours to dry shred cabbage from an initial moisture content of 94.42 % (w.b.) to a final safe moisture content of 4.85 % (w.b.). Besides, the performance of the dryer, the drying rate was faster than open sun drying and the average drying efficiency was found 8.22 % in solar tunnel dryer and 3.38% in open sun drying. Solar tunnel dryer can be used for low-temperature drying of cabbage and other agricultural products in rural areas where electricity is not available. The color, shape, and appearance of the dried cabbage were much better than open sun drying.

Contribution of the Authors

Conceptualization: Chayan Kumer Saha; Methodology: Tanjima Akter, Tafura Hoque Sharna, Chayan Kumer Saha; Formal analysis and investigation: Tanjima Akter, Tafura Hoque Sharna; Writing - original draft preparation: Tanjima Akter, Tafura Hoque Sharna; Writing - review and editing: Chayan Kumer Saha, Md. Monjurul Alam; Funding acquisition: Chayan Kumer Saha; Resources: Chayan Kumer Saha, Md. Monjurul Alam; Supervision: Chayan Kumer Saha, Md. Monjurul Alam

Acknowledgement

The authors acknowledge the Feed the Future Innovation Lab for the Reduction Post-Harvest Loss through the United States Agency for International Development (USAID) for providing fund for the experiments and necessary lab facilities during the research work at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Bangladesh. The contents are the sole responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

References

Bala, B.K. and Debnath, N. 2012. Solar drying technology : potentials and developments. *Journal of Fundamentals of Renewable Energy and Applications*, 2: 1–6. https://doi.org/10.4303/jfrea/R120302

Bala, B.K. and Mondol, M.R.A. 2001. Experimental investigation on solar drying of fish using solar tunnel dryer. *Drying Technology*, 19(2): 427–436. https://doi.org/10.1081/DRT-100102915

Bala, B.K., Mondol, M.R.A., Biswas, B.K. and Das, B.L. 2003. Solar drying of pineapple using solar tunnel drier. *Renewable Energy*, 28(2): 183–190. https://doi.org/10.1016/S0960-1481(02)00034-4

Bala, B.K. and Woods, J.L. 1995. Optimization of natural-convection, solar drying systems. *Energy,* 20(4): 285–294. https://doi.org/10.1016/0360-5442(94)00083-f

Banglapedia, 2021. https://en.banglapedia.org/index.php/Cabbage

Berinyuy, J.E., Tangka, J.K. and Weka Fotso, G.M. 2012. Enhancing natural convection solar drying of high moisture vegetables with heat storage. *Agricultural Engineering International: CIGR Journal,* 14(1): 141–148.

FAO (Food and Agriculture Organization). 2017. Statistical Year Book 2015/2016, vol.2, FAO. Rome. Retrieval from www.fao.org.

FAO (Food and Agriculture Organization). 2019. Bangladesh 3rd largest vegetable producer, national, back page. https://bangladeshpost.net/posts/bangladesh-3rd-largest-vegetable-producer-6732

Gonzales, L.M.R. and Acedo, A.L. Jr. 2016. Reducing losses of cabbage in traditional and modern chain in Cebu, Philippines. *ETP International Journal of Food Engineering*, 2(1): 48–54. https://doi.org/10.18178/ijfe.2.1.48-54

Hassan, K., 2010. A guide to postharvest handling of fruits and vegetables. *FAO,* 1(1): 1–42.

Hossain, M.Z., Alam, M.M., Hossain, M.F., Bin Sarker, M.S.H., Awal, M.A. and Jahan, N. 2018. Performance evaluation of a cabinet solar dryer for drying Red Pepper in Bangladesh. *Journal of Agricultural Engineering*, 49(2): 100–109. https://doi.org/10.4081/jae.2018.774

Janjai, S. and Keawprasert, T. 2006. Design and performance of a solar tunnel dryer with a polycarbonate cover. *International Energy Journal,* 7(3): 187–194.

Leon, M.A., Kumar, S. and Bhattacharya, S.C. 2002. A comprehensive procedure for performance evaluation of solar food dryers. *Renewable and Sustainable Energy Reviews*, 6(4): 367–393. https://doi.org/10.1016/S1364-0321(02)00005-9

Pamuk, H., Alam, M. J. and Tichar, T. 2021. Scoping study on fruits and vegetables, results from Bangladesh. Report 2021-106.54PP, Wageningen Economic Research, Wageningen, The Netherlands. https://doi.org/10.18174/553851

Parvin, M., Saha, C.K., Nandi, R. and Alam, M.M. 2021. Solar Conduction Dryer for drying of fruit and vegetables in Bangladesh. *Journal of Food Processing and Preservation*, 45(12): 1–15. https://doi.org/10.1111/jfpp.16102

Rahman, M.M., Zhou,D., Barua, S., Farid, M.S. and Tahira, K.T. 2021. Challenges of value chain actors for vegetable production and marketing in North-East Bangladesh. *GeoJournal*, 86(4): 1957–1967. https://doi.org/10.1007/s10708-020-10170-y

Sharma, V.K., Colangelo, A. and Spagna,G. 1995. Experimental investigation of different solar dryers suitable for fruit and vegetable drying. *Renewable Energy,* 6(4): 413–424. https://doi.org/10.1016/0960-1481(94)00075-H

Tomar, V., Norton, B., Schiavone, D.F., Proceedings, A.C., Lhendup, T., Thakre, P.S., Deshmukh, P.S.S., Jain, P., Engineering, H.P., Karale, S.R., Pandey, M., Acharya, S.K., Mishra, I., Basunia, M.A., Rahman, M.S., Mahgoub, O., Romuli, S., Nagle, M., Chege, C.G.K. and Cherotich, S. 2017. Design and testing of a natural convection solar tunnel dryer for Mango. *Journal of Solar Energy*, (5): 1–10. https://doi.org/10.1155/2017/4525141

Turhan, M., Turhan, K. N. and Sahbaz, F. 1997. Drying kinetics of Red Pepper. *Journal of Food Processing and Preservation*, 21(3): 209–223. https://doi.org/10.1111/j.1745-4549.1997.tb00777.x

Vega-Gálvez, A., Lemus-Mondaca, R., Bilbao-Sáinz, C., Fito, P. and Andrés, A. 2008. Effect of air drying temperature on the quality of rehydrated dried Red Bell Pepper (Var. Lamuyo). *Journal of Food Engineering*, 85(1): 42–50. https://doi.org/10.1016/j.jfoodeng.2007.06.032