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ORIGINAL ARTICLE

# Development of polyhouse type solar dryer for Kashmir valley

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**Abstract** Polyhouse type solar dryer (PSD) consist of drying chamber, drying trays and exhaust fan was developed for drying fruits and vegetables. The relative humidity (RH) inside the PSD varied in between 21 to 74% as compared to outside RH which ranged from 40 to 75%. The performance was found suitable and resulted in efficient drying at low RH. The thermal performance test for PSD under full and no load testing conditions were calculated. The temperature inside the dryer was 62 to 76% higher than the ambient conditions. PSD was helpful in reducing the drying ranging from 33 to 53%. The capacity of PSD was 100–150 kg per batch. The economic cost of solar dryer was compared with mechanical drying for beneficial to local producer. The cost of PSD Rs 80,000 could recover within the period of 1.5 years by adopting solar drying technology.

**Keywords** Solar dryer · Solar drying · Pay back period · No load testing · Full load testing

## Introduction

Solar drying is a continuous process where moisture content, air and product temperature change simultaneously along with the two basic inputs to the system i.e. the solar radiation and the ambient temperature. The drying rate is affected by ambient climatic condition which includes temperature, relative humidity, sunshine hours, available solar radiation, wind velocity, frequency and duration of rain showers during the drying period.

Kashmir valley is under temperate climate and there is severe scarcity of local fruits and vegetables from November to April. During this season cultivation of fruits and vegetables is not possible because of severe cold (Kumar et al. 2005). Drying being one of the most cost effective means of preservation of agricultural crops and foods of all varieties (Pal and Khan 2007) can be practised for rendering the surplus seasonal fruits and vegetables to be stored for longer time period. Reduction of moisture content soon after harvesting crops like apple, pear, cauliflower, cabbage, tomato, and leafy vegetables through dehydration can improve the storage life of the produce (Dwivedi et al. 2005). Joy et al. (2001) used a German made solar dryer to dry red chillies and reported that only two days were taken for optimum drying of red chillies in the solar tunnel dryer, whereas, it took 7 to 10 days in conventional method. They also found favourable results regarding better qualities like cleanliness and texture of dried products. Open sun drying has a profitable activity, but it has some associated problems like damage due to rain, insect, dust and dirt contamination (Kadam and Samuel, 2006). This results not only in deterioration in quality of produce but also affects appearance, nutrient quality and shelf life adversely (Dwivedi et al. 2003). The use of a solar tunnel drier and blanching of sample led to a considerable reduction in drying time and better quality dried products in terms of colour and pungency in comparison to products dried under the sun (Hossain and Bala 2007). In the mechanical dryers, fuel wood, petroleum fuel, coal or electricity is used for air heating. Mechanical drying is costly in terms of both capital and operational cost.

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Solar air dryers may be alternative to industrial scale drying of industrial and agricultural products because of its low cost. Therefore, there is a need for a system to dehydrate fruits and vegetables under hygienic conditions so as to extend their availability during off-season. Preservation of leafy vegetables can prevent huge wastage as well as make them available in the lean season (Pande et al. 2000). Further, there is acute crisis of electric power and other forms of fuel like wood, kerosene oil, and coal in the Kashmir valley. Shahi Navin et al. (2009) fabricated a solar poly tunnel dryer (SPTD) for fruits and vegetables for Kashmir valley. As compared to conventional dryer, the SPTD had low cost and it was helpful in decreasing the time consumption by 50–70% for dehydration. Keeping in view all these facts, a study was initiated to develop and evaluate a Polyhouse type solar drier suitable for Kashmir valley in order to harvest the abundant sunshine available.

## Materials and methods

The study was conducted under All India Coordinated Research Project on Application of Plastics in Agriculture, at Division of Agricultural Engineering SKUAST (K), Srinagar. A polyhouse type solar dryer (PSD) having a loading capacity of 1 to 1.5 quintal of fresh fruits and vegetables per batch was developed and fabricated in this division. The specifications of PSD are illustrated in Fig. 1. The experiments were conducted on selected fruits and vegetables like tomato, capsicum, cabbage, leafy vegetable, carrot and apple during the month of August, 2007. The drying materials were cut into thin slices of 5±1 mm and were uniformly spread on trays placed in trolly. The cut pieces of fresh fruits and vegetables (e.g. carrot) were first blanched at 90°C for 3 min and then about 3.5 kg per tray carrot slices were dried. Drying was carried out for 8 h a day.

## Design consideration

PSD consisted of basically a drying chamber, small exhaust fan and a metal duct. The dryer was covered with a transparent UV stabilized polyethylene plastic foil of 0.2 mm thickness with a transmittivity of 92% for visible radiation which traps the solar energy in the day time and enhance the temperature inside to maintain it at optimum level for drying of fruits and vegetables. The top surfaces of the collector and drying chamber were designed in curved shape in order to increase the area of radiation. They were made to open and close easily for the function of spreading the drying commodity at the beginning of the day and clean the polyethylene cover. In order to reduce the heat loss, a metal duct was provided outside the exhaust fan. The inclination of top surface of the dryer was kept 30°. It was positioned in north–south direction so that, radiation from the sun would not be disturbed. The drying tunnel have length of 5 m, breath of 4 m, central height of 3.2 m and side heights of 2.5 m left and 1.5 m right. The polyethylene cover served as a solar heat absorber. The capacity of the tunnel ranged from 1 to 1.5 quintal of fresh fruits and vegetables depending upon the material and thickness of the spreading layer.

The cement concrete floor was painted black for better absorption of solar radiation. To reduce heat loss through the floor, 2″ thick glass wool insulation was provided. A black body was installed for better absorption of solar and reducing heat losses from the northern side of polyhouse. Inlet for fresh air was provided in south wall of the polyhouse near ground level. West wall of polyhouse was fabricated with a steel door of 2 m×1 m size for loading and unloading of the material and a fan of 1,000–1,200 $m^3$/h air flow rate capacity and 1 kW power was installed. A trolley is located at north wall of dryer. It has two shelves of 5×1.5 m size at 0.8 and 1.6 m height from the floor respectively. Each shelf contains 20 trays of 0.5 m×0.6 m×0.05 m dimension in two rows. The cost of the Polyhouse dryer is Rs 80,000.

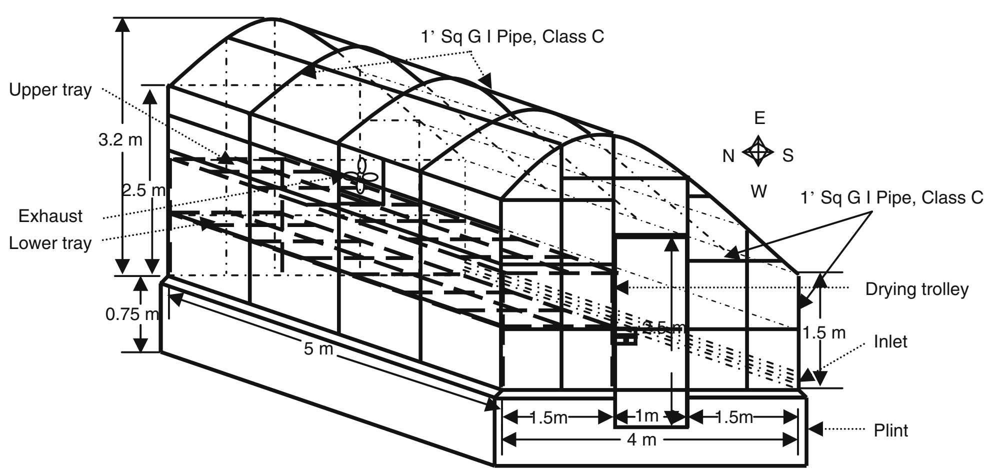


**Fig. 1** Schematic representation of the Polyhouse type Solar Dryer

**Performance evaluation of PSD**

The drying in a solar dryer depends on outside environmental conditions, mainly temperature and relative humidity (RH). Ambient air temperatures and RH profile inside the dryer were recorded using digital thermo-hygrometer (Temperature range: -50 to70°C, humidity range: 10 to 99%, accuracy: ± 1°C, ± 5%) at lower and upper tray for 8 h a day at an interval of 1 h from 9:00 to 17:00 h. Temperature and relative humidity were obsrerved in triplicate. Outside air temperature was also measured at the same time under ambient conditions. The performance of the dryer was evaluated under no load testing and full load testing (Singh et al. 2007). Tomato, capsicum, carrot, cabbage, leafy vegetable and apple were dried using PSD and by sun drying.

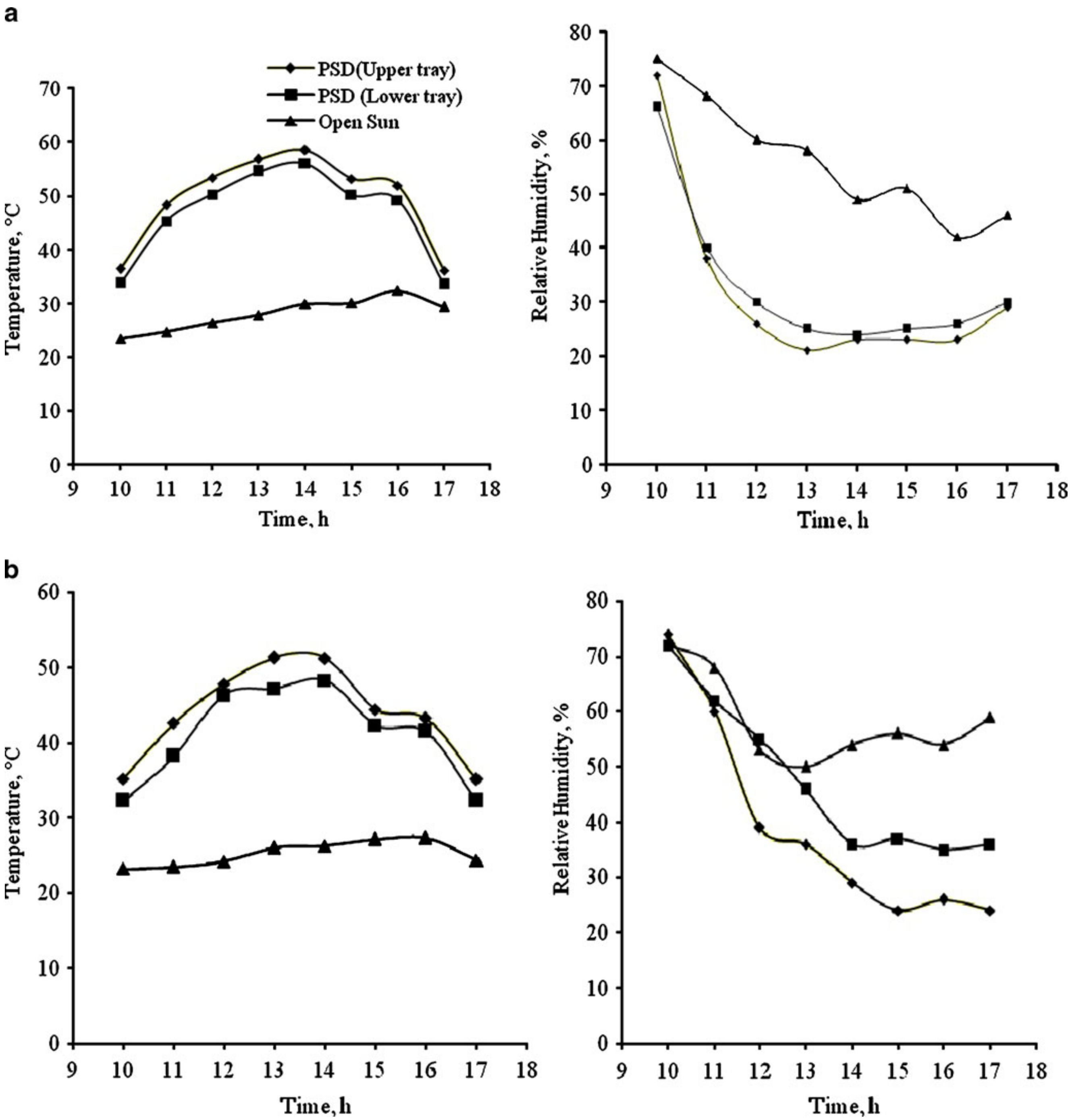


**Fig. 2** Effect of solar radiation on ambient air temperature and relative humidity for 20th August 2007 under no load condition **a** 21st August 2007 under full load condition **b** ($n$=3)

## Economic evaluation

Based on working performance of solar dryer, different direct benefits were derived. These benefits were indicators of technical feasibility of dryer. Subsequently the economics of this dryer was evaluated in term of cost per kg of food through fuel back up in PSD. Yearly benefit of PSD was compared to conventional drying backup unit in terms of electricity saving. The payback period of the dryer for carrot was calculated including fixed cost, variable cost (labour, electricity, processing, samples costs etc.) and margin or income from the dryer per year.

Energy required to remove kilogram of moisture from carrot in PSD is given by number of days effectively used for drying per year=200 days

Number of days required for drying carrot per batch= 3 days

Fresh carrot drying per year=10,000 kg

Water removed from 10,000 kg of carrot by drying it from 87% to 6% moisture content (wet basis)=8,617 kg

Energy required to dry the food is given by (Sengar et al. 2009)

$$E = m \times s \times \Delta t + m_1 L_v$$

where,

- m mass of fresh carrot (10,000 kg)
- s specific heat of the material (0.91 kcal/kg °C)
- $\Delta t$ temperature difference (25°C)
- $L_v$ latent heat of vaporization at 60°C (564 kcal/kg)
- $m_1$ mass of water evaporated during drying (8,617 kg)

Heat required to dry 10,000 kg fresh carrot:

$$= 10,000 \times 0.91 \times 25 + 8,617 \times 564$$
$$= 5.08 \times 10^6 \text{kcal}$$

**Table 1** Comparative performance of polyhouse type solar drier with open sun drying for different fruits and vegetables

| Product | Moisture | | PSD, hours | OSD, hours |
|---|---|---|---|---|
| | [a]Initial,% wb | Final,% wb | | |
| Tomato | 93.8 | 8.2–10.4 | 21 | 38 |
| Capsicum | 92.2 | 3.8–5.6 | 21 | 32 |
| Cabbage | 92.8 | 3.6–6.8 | 18 | 32 |
| Spinach | 92.4 | 3.2–5.6 | 14 | 32 |
| Carrot | 86.8 | 4.4–8.2 | 21 | 32 |
| Apple | 84.2 | 4.6–8.6 | 25 | 52 |

[a] (*n*=3 replication)

*PSD* Polyhouse type solar dehydration, *OSD* Open sun drying

**Table 2** Payback period of PSD for carrot drying

| | |
|---|---|
| A) Fixed capital, Rs | 80,000 |
| B) Working capital per year, Rs | |
| i) Raw material cost (carrot) @ Rs 10/kg | 100,000 |
| ii) Labour cost @ 3,000 monthly | 36,000 |
| iii) Maintenance cost (3% of initial cost) | 2,400 |
| iv) Cost of electricity to drive fan per month @ Rs 4/kWh | 3,200 |
| C) Interest @ 12% (Rs) | 13,848 |
| C) C) Depreciation (10% p.a.), Rs | 8,000 |
| D) Processing cost @ Rs 76 per batch | 5,000 |
| E) Annual cost, Rs | 168,448 |
| F) Total sale per annum | |
| Carrot powder (1,383 kg @ Rs 160) | 221,280 |
| G) Annual profit | 52,832 |
| Pay back period, years | 1.5 |

Now suppose this energy is supplied by mechanical dryer and efficiency of dryer is 80%, then actual energy required per year

$$= 6.35 \times 10^6 \text{ kcal} = 7373\text{kWh}$$

## Results and discussion

PSD performance was compared between ambient environment conditions for period of experimentation during particular days, 20th August under no load and 21st August, 2007 under full load conditions. The trends of ambient and PSD air temperature and RH under no load and full load conditions are shown in Fig. 2.

It is evident from Fig. 2 that the temperature difference inside and outside of the drier was low in the morning and evening periods as compared to afternoon, when temperature difference was high. Similar trends were observed for RH difference, which contradicts Kadam and Samuel (2006) and similar to the results stated by Shahi Navin et al. (2009). The reason for this contradiction is that the PSD contains an exhaust fan at the top of the north wall which removes excess humid air inside the chamber. The increases in ambient air temperature as well as decrease in the RH inside and outside of PSD are directly affected by solar radiation (Kadam and Samuel 2006). The inside and outside RH were inversely proportional to solar radiation.

### Relation between ambient temperature and RH inside and outside the SPTD

The relation of air temperature at upper ($T_{Uin}$) and lower ($T_{Lin}$) trays inside the dryer with outside ambient temperature

($T_o$) were estimated and a linear correlation was obtained with the value of $R^2$ 0.7164 and 0.7612 respectively.

$$T_{Uin} = 3.44T_o - 41.85$$
$$T_{Lin} = 3.60T_o - 48.89$$

The relation between relative humidity of air at upper ($H_{Uin}$) and lower ($H_{Lin}$) trays inside dryer and in ambient ($H_o$) was formulated and a linear correlation was attained with a value of $R^2$ 0.7799 and 0.8032 respectively.

$$H_{Uin} = 1.52H_o - 46.96$$
$$H_{Lin} = 1.39H_o - 39.76$$

## Solar drying operation

*No load testing* The highest temperature attained inside the dryer under no load condition was 58.6°C at 14:00 h at the upper tray while the lowest was 33.4°C at 10:00 h and 17:00 h at the lower tray (Fig. 2). The temperature recommended by Dauthy (1995) for quick dehydration of fruits and vegetables was 66–71°C and 60–66°C respectively. The average temperature inside the PSD drier was 76% and 66% higher than the average ambient temperature at upper and lower tray respectively. The maximum RH attained inside the dryer under no load condition was 72% at 10:00 h at the upper tray while the minimum was 21% at 13:00 h at the upper tray (Fig. 2). These results are in agreement with the observation of earlier workers (Kouhila et al. 2002; Lahsasni et al. 2004; Shahi Navin et al. 2009).

*Full load testing* The highest temperature attained inside the dryer under full load condition was 51.3°C at 13:00 h at the upper tray while the lowest was 32.2°C at 10:00 h and 17:00 h at the lower tray (Fig. 2). The temperatures obtained using PSD were equivalent to the temperature obtained using Solar dryer cum cooker cabinet under no load testing conditions (Sengar and Kurchania 2007). The average temperature inside the PSD drier was 44% and 41% higher than the average ambient temperature at upper and lower trays respectively. The maximum RH attained inside the dryer under full load condition was 74% at 10:00 h at the upper tray while the minimum was 24% at 15:00 h and 17:00 h at the upper tray (Fig. 2). These results are in agreement with the observation of earlier researchers (Müller et al. 1989; Kouhila et al. 2002; Lahsasni et al. 2004; Shahi Navin et al. 2009; Amer et al. 2010).

The drying time of selected fruits and vegetables using PSD was compared with open sun drying, experimental data obtained are given in Table 1. It was observed that PSD was helpful in decreasing the time taken for dehydration by about 40–55%. Similar result was found by Janjai et al. 2009 and Montero et al. 2010 for peeled banana and olive pomace respectively. The high temperature coupled with proper air circulation produced a higher drying rate in PSD as compared to open sun drying leading to reduction in dehydration time.

## Economic comparing with conventional drying backup unit

The total cost of PSD was Rs 80,000 including material and manufacturing cost. Approximately 7,373 kWh of electricity was required for obtaining yearly output, if PSD unit was not used. If electricity unit charge was taken as Rs 3.00; the cost of unit equivalent of electrical backup would be Rs 22,119 for a year. The payback period of PSD was also calculated. It was observed that the initial investment would be recovered with in the period of 1.5 year approximately (Table 2).

## Conclusion

The poly house type solar dryer was designed and fabricated. PSD was tested and found better than open sun drying in terms of time consumption and hygienic conditions. The temperature and humidity inside the PSD was found linearly correlated with the outside respectively. Cost of PSD Rs 80,000 could be recovered within the 1.5 years.

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## References

Amer BMA, Hossain MA, Gottschalk K (2010) Design and performance evaluation of a new hybrid solar dryer for banana. Energy Convers Manage 51:813–820

Dauthy ME (1995) General procedures for fruit and vegetable processing. In: Fruit and vegetable processing. FAO Agricultural Services Bulletin 119, International Book Distribution Co, Lucknow, pp 40–57

Dwivedi D, Massarat S, Mir AA (2003) Solar dehydration of tomatoes in Ladakh. In: National Symp Resource Management for Eco-friendly Crop Production, February 26–28, CSAUT, Kanpur, p 175

Dwivedi SK, Narboo S, Kareen A, Ahamd Z (2005) Designing and development of low cost polyhouse drier. J Rural Technol 1:281–283

Hossain MA, Bala BK (2007) Drying of hot chilli using solar tunnel drier. Sol Energy 81:85–92

Janjai S, Lamlert N, Intawee P, Mahayothee B, Bala BK, Nagle M, Müller J (2009) Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana. Sol Energy 83:1550–1565

Joy CM, George PP, Jose KP (2001) Solar tunnel drying of red chillie (*Capsicum annum L.*). J Food Sci Tech 38:213–216

Kadam DM, Samuel DVK (2006) Convective flat-plate solar heat collector for cauliflower drying. Biosystems Eng 93:189–198

Kouhila M, Kechaou N, Otmani M, Fliyou M, Lahsasni S (2002) Experimental study of sorption isotherms and drying kinetics of Moroccan eucalyptus globules. Drying Technol 20:2027–2039

Kumar A, Kadam DM, Thaware JB, Indu Bhagat B (2005) Performance of gothic shape with vertical sidewall greenhouse structure in cold desert region of India for crop production. Plasticulture II Epoca 124:90–105

Lahsasni S, Kouhila M, Mahrouz M, Jaouhari JT (2004) Drying kinetics of prickly pear fruit (*Opuntia ficus indica*). J Food Eng 61:173–179

Montero I, Blanco J, Miranda T, Rojas S, Celm AR (2010) Design, construction and performance testing of a solar dryer for agro-industrial by-products. Energy Convers Manage 51:1510–1521

Müller J, Reisinger G, Kisgeci J, Kotta E, Tesic M, Mühlbauer W (1989) Development of a greenhouse-type solar dryer for medicinal plants and herbs. Sol Wind Technol 6:523–530

Pal US, Khan M (2007) Heat pump drying of food materials: a critical review. J Food Sci Technol 44:119–124

Pande VK, Philip SK, Sonune AV (2000) Solar drying of coriander and methi leaves. J Food Sci Technol 37:592–595

Sengar SH, Kurchania AK (2007) Design development and testing of composite solar dryer cum cooker. J Food Sci Technol 44:375–377

Sengar SH, Khandetod YP, Mohod AG (2009) Low cost solar dryer for fish. Afr J Environ Sci Technol 3:265–271

Shahi Navin C, Pandey H, Feeza AM (2009) Development and performance evaluation of solar poly tunnel dryer for Kashmir valley. J Food Sci Tech 46:263–265

Singh P, Rathore NS, Mathur AN (2007) Development of solar tunnel dryer for industrial use. J Agril Eng 44:92–95