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Drying characteristics and value addition of horticulture crops using thermally efficient indirect solar drier with temperature controller system

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Abstract
In the present investigation, apple and tomato were dried in three modes of drying viz. indirect solar drier, electric drier and open sun. The shelf life and quality parameters of dried products were compared between these three modes of drying. It has been found that shelf life of dried products dried in solar drier is higher than other modes of drying. The quality parameters such as, TSS, reducing sugars, total sugars, total solids and titratable acidity of dried products were better in solar drier as compared to other modes of drying. The drying efficiency of the solar drier ranged between 33.84% to 40.45%. The carbon emission has been reduced in solar drier as compared to electric oven between 15.52 to 19.83 kg.

Keywords: Drying characteristics, horticulture crop, thermally efficient, indirect solar, temperature controller system

1. Introduction
The global population is likely to reach around nine billion by 2050. Food security will be a major concern in large parts of the developing world. Food production must increase significantly to meet the future demands of an increasing and more affluent world population. Roughly one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year. Approximately 52% of fruits and vegetables are lost between the harvest and consumption (FAO, 2011) [1]. Overall, on a per-capita basis, much more food is wasted in the industrialized world than in developing countries.
In India, the production is about 450 million tons of raw food materials of plant and animal origin out of this amount there is 10 per cent post-harvest losses in durables (Cereals, pulses and oilseeds), 20 per cent losses in semi-perishables (Potato, onion, sweet potato, tapioca) and around 25 per cent in products like milk, meat, fish and eggs. Furthermore, In India, annual storage losses estimated to be 14 million ton of food grains worth $ 16,000 million every year. About from 30 per cent to 40 per cent of the fruits and vegetables grown in India (40 million tons amounting to US$ 13 billion) get wasted annually due to gaps in the cold chain such as poor infrastructure, insufficient cold storage capacity, unavailability of cold storages in close proximity to farms, poor transportation infrastructure, etc. (Rajasri *et al*., 2010; Maheshwar and Chanakwa, 2006; Rolle, 2006; Ali, 2004) [2, 3, 4, 5]. On the basis of production and wholesale market price in India, the Associated Chambers of Commerce and Industry of India (ASSOCHAM) found that fruits and vegetables post - harvest losses reached to $33,745 million in 2013-14 [6]. Several investigators have attempted to estimate post-harvest losses of fruits in Himachal Pradesh. Out of total production, the post-harvest losses in selected fruits in Himachal Pradesh namely apple (Singh, 2002) [7], mango, peach and kinnow (Prasher and Negi 2000) [8] were 14.48, 24.85, 18.31 and 24.5%, respectively. The losses were more at wholesaler's/ retailer's level in all the selected fruits except apple.
The best way to reduce the post harvest losses is the drying of crops. Although, the traditional drying in open is of low cost and it does not involve technology but, it has many drawbacks such as, contamination of the product due to dirt and insects, effect of birds and mice, spoilage due to erratic weather, uncontrolled temperature, damage by wild animals, labour intensive and low market rates. Also, loss of vitamins, nutrients and unacceptable colour changes due to direct exposure to ultraviolet rays, it takes long time to dry. However, drying in solar drier has many advantages such as significant enhancement in quality of the dried product, reduction in

drying time, improves drying hygiene, no effect of insects, protection from erratic weather & wild animals, higher market rates of dried products and reduces CO2 emissions (Aggarwal, 2018) [9]. The solar dryers of variegated types can be made locally and of any size, design and capacity. The solar drier helps to overcome the problem of open sun drying, which consists of a collector, a drying chamber and an exhaust fan or chimney (Madhlopa *et al*, 2002) [10]. The main purpose of drying is to improve the shelf life of dried products.

Several direct and indirect solar driers have been developed world wide. In Himachal Pradesh a 1000 kg capacity direct solar drier was developed for the extraction of chilgoza seeds and five solar driers were installed at high altitude areas of Kinnaur district (Aggarwal, 1998) [11]. A 25 kg indirect solar drier was developed for the drying of fruits and vegetables under the project funded by Department of Science and Technology, GOI, New Delhi (Aggarwal *et al*, 2010) [12]. 15 such solar driers were installed in the state under the project funded by TATA Trust, Mumbai (Aggarwal, 2012) [13]. Ankush *et al*, 2018 [14] and Ankush *et al*, 2019 [15] have also dried some wild fruits in indirect solar drier with good quality of dried products. The temperature inside the solar drier remained the problem for the drying of various fruits and vegetables, as the temperature increases the fruits get damage. This problem was sorted out with the introduction of temperature controller in indirect solar drier (Aggarwal *et al*, 2018) [16]. In the present study, two crops were dried in the newly developed indirect solar drier.

2. Methodology

Two crops viz. Apple and Tomato were dried to evaluate the performance of solar drier in comparison to cabinet drier (oven) and open sun drying. Two sets of each sample (i) pre-treated (Table 1.) and (ii) without treatment were prepared and dried with three different modes of drying. In case of apple, it was treated with 0.3 per cent potassium metabisulphite + 0.20 per cent citric acid for about 10 minutes after blanching. Whereas, in case of tomato, the slices were treated with 1 per cent calcium chloride + 0.25 per cent potassium metabisulphite for about 8-10 minutes. The detail of different treatment combinations are:

$P_1/D_1/R_1$= Open sun without treatment (control)
$P_2/D_2/R_2$= Open sun with treatment
$P_3/D_3/R_3$= Solar drier with treatment
$P_4/D_4/R_4$= Solar drier without treatment
$P_5/D_5/R_5$= Cabinet drier with treatment
$P_6/D_6/R_6$= Cabinet drier without treatment

The weight of the samples was recorded periodically to find out the drying rate. The temperature variation in the three modes of drying was recorded on hourly basis with temperature and humidity sensors. The moisture content of products was recorded using automatic moisture balance. The water activity of dried products was observed using water activity meter. The temperature in the cabinet drier was kept at 50^0C and it was intermediate drying from 10 AM to 5 PM.

2.1. Drying efficiency

The drying efficiency of solar drier has been calculated using formula

η=ML /I Ac

Where
η is drying efficiency
M = Mass of moisture evaporated per sec (Kg/s)
L = Latent heat of evaporation of water (kJ/Kg)
I = solar radiation (W/m2)
Ac = Collector area (m2)

2.2. Carbon reduction

The carbon reduced during drying of crops in comparison to cabinet drier has been estimated using following formula

C = power of cabinet drier x number of hour /1000 x 0.87 (kg)

2.3. Physico chemical and sensory quality evaluation:

All the physico-chemical parameters like moisture content (W/W), total solids, titratable acidity (%), pH, water activity, total soluble solids (ºBrix), total sugars (%), reducing sugars (%), drying time (hours) and drying rate (gm/h) were recorded as per standard methods (Ranganna, 1997 [17]). The sensory evaluation of the dried fruit samples was carried out by 9-point Hedonic rating test as given by (Amerine 1965 [18]). The prepared samples were evaluated for sensory qualities on the basis of colour, texture, taste and overall acceptability on a 9-point hedonic scale.

2.4. Drying cost

The cost of drying has been calculated on the basis of current market prices of raw material, nominal processing charges, depreciation on machinery and reasonable profit margins.

2.5. Statistical analysis

The data pertaining to physio-chemical characteristics of dried fruits before and during storage were analyzed by CRD (factorial) and data pertaining to the sensory characteristics was analyzed by RBD (Cochran and Cox, 1967 [19]). The experiments were replicated three times.

3. Results and Discussion

3.1. Drying efficiency: The drying efficiency of solar drier has been calculated during drying of various crops and has been summarized in table 1. The table revealed that drying efficiency of solar drier varies from 33.84% to 40.45%.

Table 1: Drying efficiency of various crops dried in solar drier

Crops	Drying efficiency (%)
Apple	33.84
Tomato:	40.45

3.2. Carbon reduction in drying of crops: The carbon reduction has been calculated during drying of crops in solar drier as compared to electric oven. The table 2 revealed that carbon reduction ranged between 15.52 to 19.83 kg.

Table 2: Carbon reduction in drying of crops in solar drier

Crops	Carbon reduction in kg
Apple	15.52
Tomato	19.83

3.3. Drying time: The drying time for the drying of crops has been observed in three different modes of drying. The table 3 revealed that the drying time of crops in solar drier is less than the open sun drying. However, the samples dried in electric oven took less time as compared to other mode of drying.

Table 3: Drying time of crops in three modes of drying

Crops	Drying time (hrs)		
	Solar drier	Open sun	Oven
Apple	30	32	28
Tomato	33	36	31

3.4. Cost of drying: The cost per kg of crops drying in solar drier and electric oven was calculated. The table 4 revealed that cost per kg crop drying in solar drier ranged between Rs. 62.51 to 65.89 whereas, drying cost in electric oven ranged between Rs. 139.70 to 150.39.

Table 4: Cost of drying

Crops	Cost (Rs.)	
	Solar Drier	Oven
Apple	62.51	139.70
Tomato	65.89	150.39

3.5. Shelf life of dried products
Table 5. revealed that products dried in solar drier have low values of water activity initially, after 1 month and after 3 months. The water activity value less than 0.5 is considered to be best for shelf life of dried products. The water activity of Apple dried in open sun is higher followed by dried in electric oven and solar drier. The table shows that solar dried products have long shelf life and can be stored for longer period of time.

Table 5: Shelf life of dried products

Name of crop	Mode of drying	Water activity (month)		
		0	1	3
Apple	Open sun T1	0.559	0.562	0.571
	Solar drier T3	0.419	0.425	0.452
	Electric drier T5	0.501	0.511	0.520

3.6. Temperature variation in tomato
The temperature variation during the drying of tomato in open sun, electric drier and solar drier has been presented in Fig 1 to Fig 3. The data reveals that the collector temperature and drying chamber temperature remained above the open sun temperature. This reduces the drying time inside the solar drier. The temperature inside the collector and drying chamber remained above the open sun even after sunset due to thermal storage system provided at the bottom of solar collector.

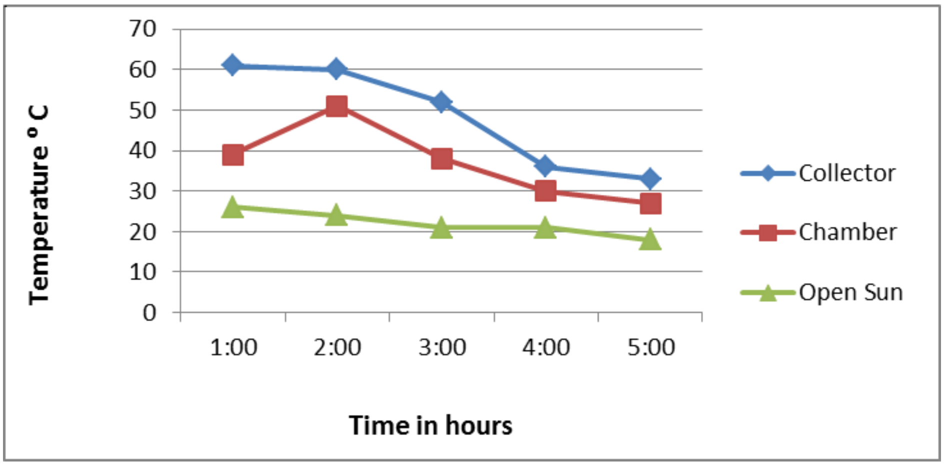


Fig 1: Temperature variation with time during 1st day of drying in tomato

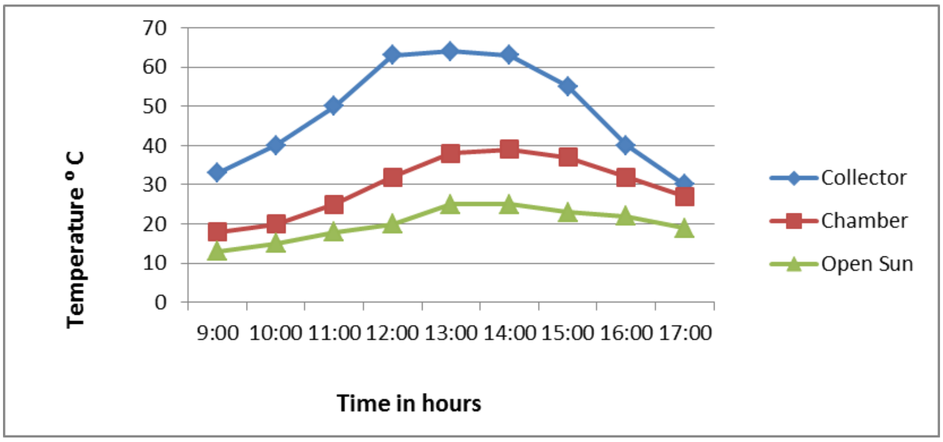


Fig 2: Temperature variation with time during 2nd day of drying in tomato

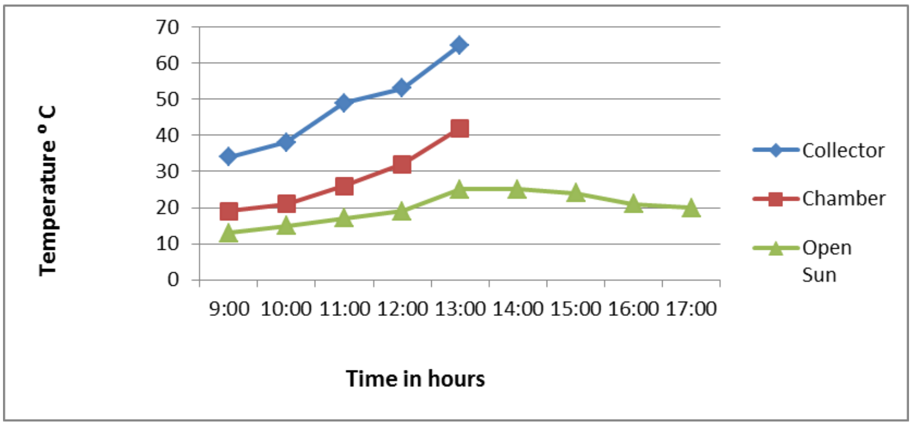


Fig 3: Temperature variation with time during 3rd day of drying in tomato

3.7. Humidity variation in tomato

The humidity variation during the drying of tomato in open sun and solar drier has been presented in Fig 4 to Fig 6. The Fig 4 indicates that during the initial stage of drying the humidity in drying chamber is lower than the open sun. But as drying continues the humidity in the drying chamber increased due to removal of water content from the tomato. The Fig 5 revealed that on 2nd day the humidity in drying chamber stats decreasing and remained below the open sun. This indicates the removal of water content in drying chamber faster than the open sun. The Fig 6 shows that after three days of drying the water content in tomato has reduced to minimum in solar drier.

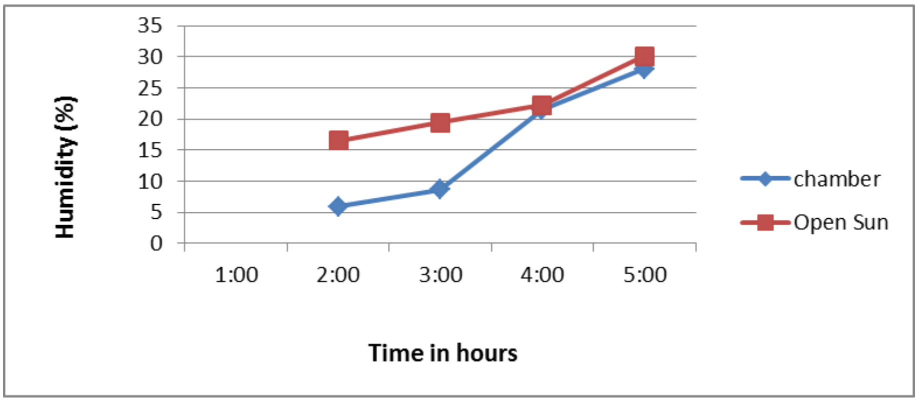


Fig 4: Humidity variation with time during 1st day of drying in tomato

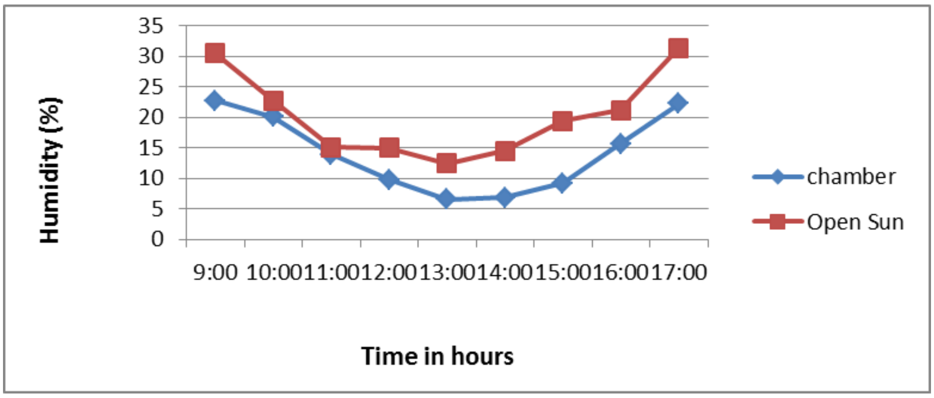


Fig 5: Humidity variation with time during 2nd day of drying in tomato

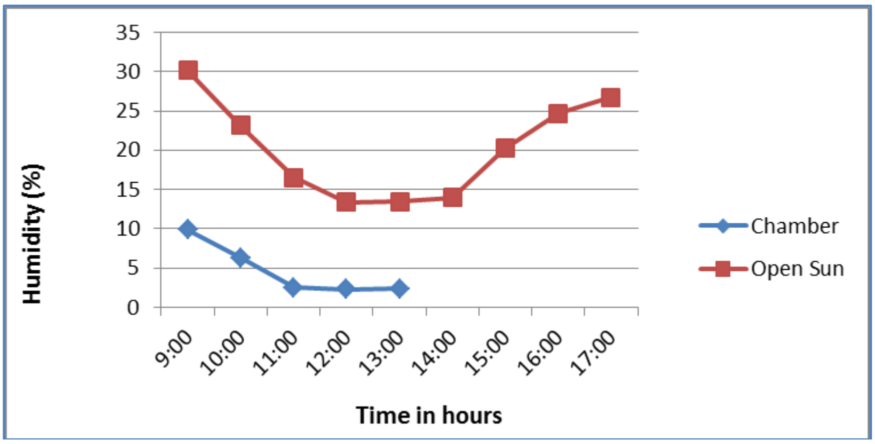


Fig 6: Humidity variation with time during 3rd day of drying in tomato

3.8. Temperature variation in Apple

The temperature variation during the drying of peas in open sun, electric drier and solar drier has been presented in Fig 7 to Fig 10. The data reveals that the collector temperature and drying chamber temperature remained above the open sun temperature. This reduces the drying time inside the solar drier. The temperature inside the collector remained above the open sun even after sunset due to thermal storage system provided at the bottom of solar collector.

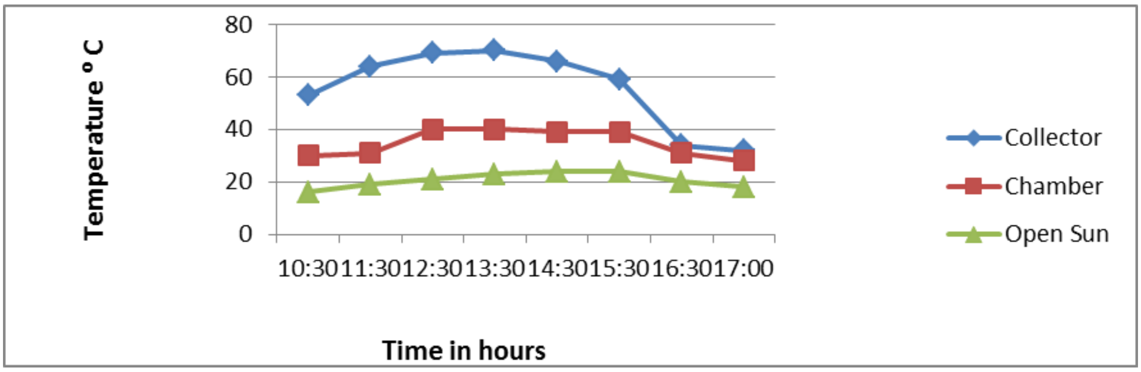


Fig 7: Temperature variation with time during 1st day of drying in Apple

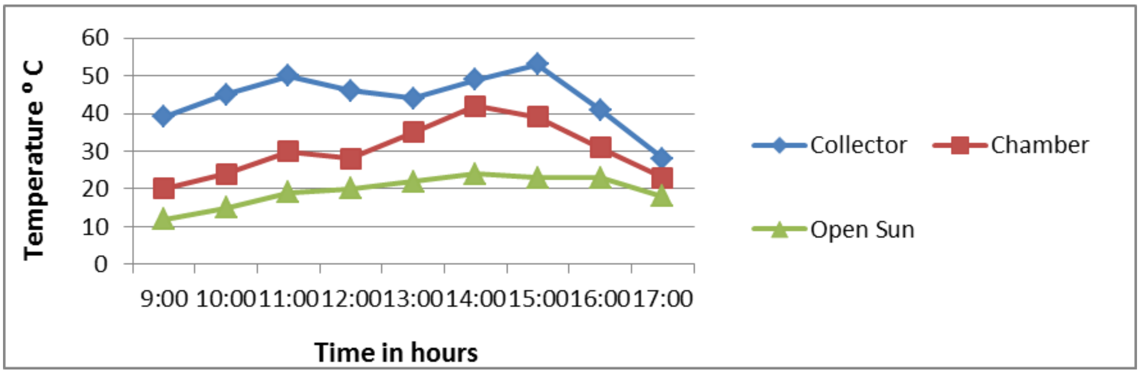


Fig 8: Temperature variation with time during 2nd day of drying in Apple

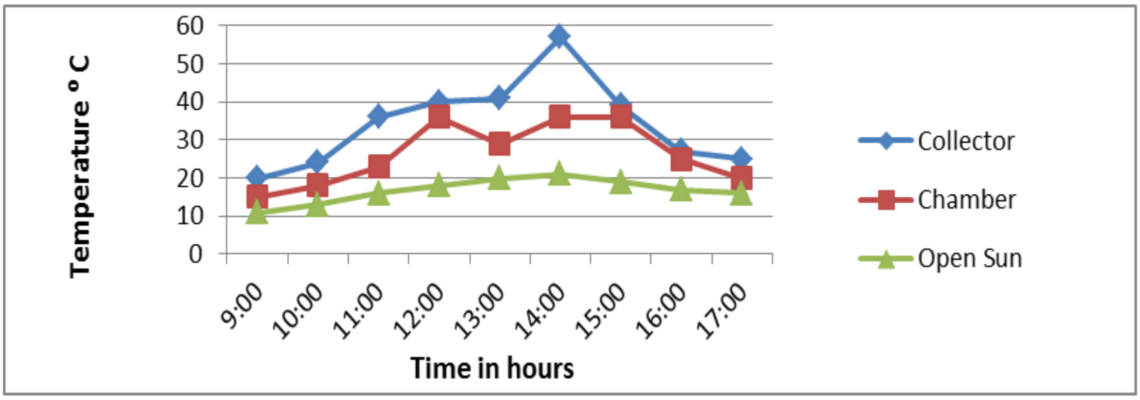


Fig 9: Temperature variation with time during 3rd day of drying in Apple

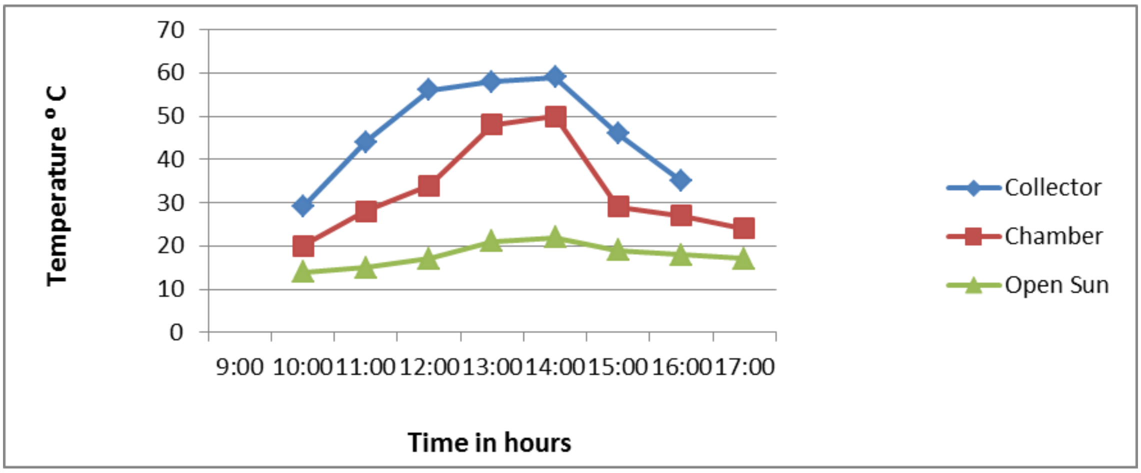


Fig 10: Temperature variation with time during 4th day of drying in Apple

3.9. Humidity variation in Apple

The humidity variation during the drying of tomato in open sun and solar drier has been presented in Fig 11 to Fig 14. The Fig 11 indicates that the humidity in drying chamber initially remains lower during than the open sun. But during evening the humidity in drying chamber is above the open sun due removal of moisture present in crop. During the 2nd day the humidity in the drying chamber remains below the open sun which indicates that crop starts drying (Fig 12). During 3rd and 4th days the removal of water content in fruit was very fast (Fig 13 and 14).

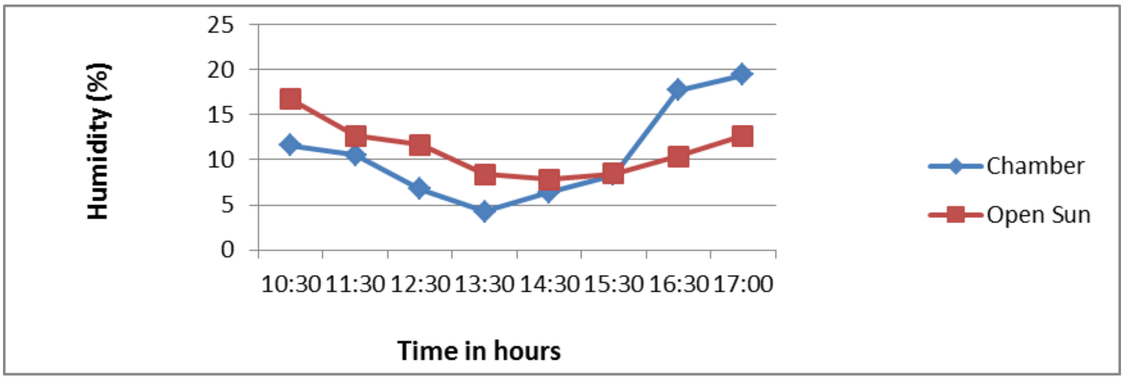


Fig 11: Humidity variation with time during 1st day of drying in apple

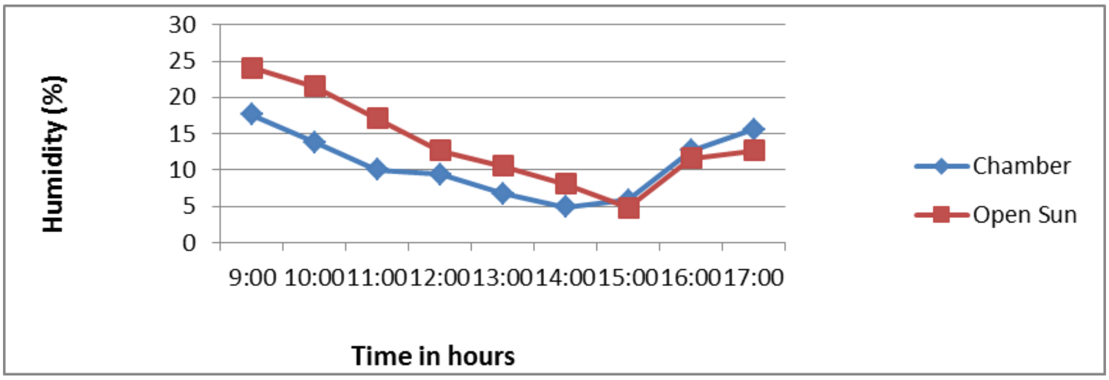


Fig 12: Humidity variation with time during 2nd day of drying in apple

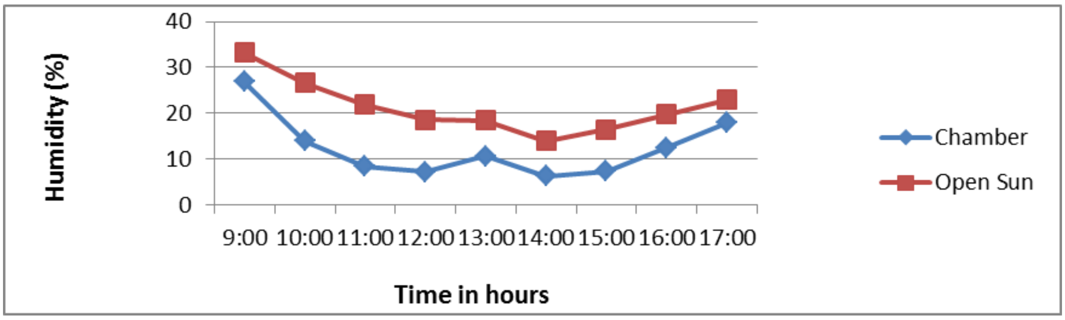


Fig 13: Humidity variation with time during 3rd day of drying in apple

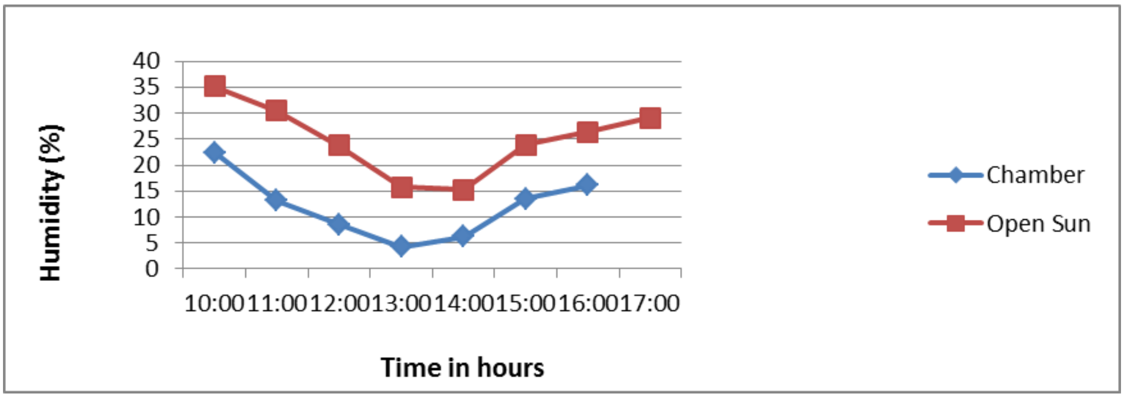


Fig 14: Humidity variation with time during 4th day of drying in apple

3.10 Quality parameters of dried products

Apple and tomato were dried to analyze the quality parameters like TSS, reducing sugars, total sugars, total solids and titratable acidity of dried products were compared with three modes of drying viz. solar drier, open sun and electric oven. Water activity of dried products was also recorded to find out the shelf life of dried products. The samples (with treatment and without treatment) of each crop were dried in three modes of drying. The quality parameters of dried products have been summarized in table 6 and table 7.

The water activity of Apple was minimum (0.311) of treated sample dried in solar drier resulting high shelf life (Table 6). The titratable acidity was highest (2.93%) in untreated sample dried in open sun, TSS was maximum (33.0^{0}brix), reducing sugar was highest (28.77%) and total sugar (29.88%) was highest in treated sample dried in solar drier. Hence, the solar dried sample was best among the three modes of drying.

Table 6: Quality parameters of Apple

Parameters / Treatments	Moisture content %	Total solids	Water activity	Titratable acidity %	TSS ^{0} Brix	Reducing sugar %	Total sugar %
T1	11.13	88.87	0.400	2.91	30.50	26.11	27.83
T2	11.52	88.48	0.428	2.93	29.50	25.90	26.42
T3	9.41	90.59	0.311	2.44	33.00	28.77	29.88
T4	9.55	90.45	0.321	2.49	30.75	26.89	27.71
T5	9.52	90.48	0.331	2.68	32.00	27.81	28.89
T6	9.58	90.42	0.352	2.70	30.50	26.55	27.77
Fresh	88.70	11.30	0.798	0.41	12.11	9.17	10.38

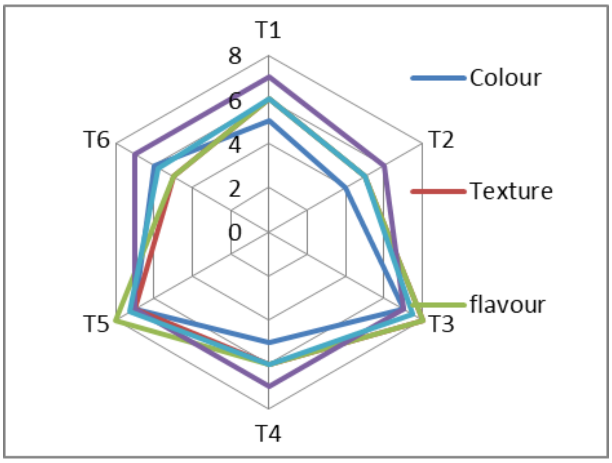
The water activity of Tomato was minimum (0.286) of treated sample dried in solar drier resulting high shelf life (Table 7). The titratable acidity was highest (3.82%) in treated sample dried in open sun, TSS was maximum (26.54^{0}brix), reducing sugar was highest (21.73%) and total sugar (22.19%) was highest in treated sample dried in solar drier. Hence, the solar dried sample was best among the three modes of drying.

Table 7: Quality parameters of Tomato

Parameters / Treatments	Moisture content %	Total solids %	Water activity	Titratable acidity %	TSS ^{0} brix	Reducing sugar %	Total sugar %
T1	14.73	85.27	0.419	3.82	22.13	17.71	18.02
T2	15.77	84.23	0.443	3.75	21.95	16.79	17.68
T3	10.11	89.89	0.286	3.51	26.54	21.73	22.19
T4	12.59	87.41	0.324	3.42	25.73	20.66	21.59
T5	10.51	89.49	0.361	3.70	23.11	18.49	19.10
T6	12.60	87.40	0.393	3.61	22.95	17.91	18.78
Fresh	95.43	4.57	0.960	1.24	11.23	8.53	9.67

3.7. Sensory characteristics of dried products

Data related to texture, colour, taste and overall acceptability of dried products is presented in Fig 15 and Fig 16. Data showed that maximum 9 point hedonic scale score for texture, colour, taste and overall acceptability was given to fruit dried in solar dryer. Highest score for colour, texture, taste and overall acceptability was given to treated fruit dried in solar dryer due to non exposure of sample to direct sun. Additive, like potassium metabisulfite and citric acid inhibit the browning reaction by binding with the carbonyl group of reducing sugars and other compound to retard the browning process, result in good colour, flavor of dried product.



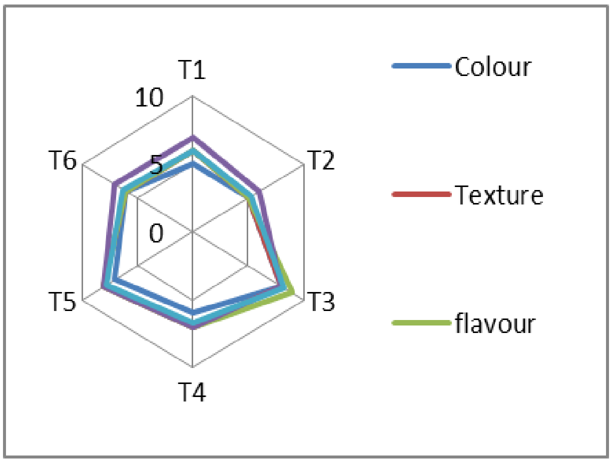


Fig 15: Sensory quality parameters of Tomato

Fig 16: Sensory quality parameters of Apple

T1= Open sun with treatment, T2= Open sun without treatment, T3= Solar drier with treatment
T4= Solar drier without treatment, T5= Cabinet drier with treatment, T6= Cabinet drier without treatment

4. Acknowledgement
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5. Conclusions
Two crops were dried in indirect solar drier having thermal storage system and temperature controller. The results revealed that water activity of sample dried in solar drier was less as compared to other mode of drying indicates longer shelf life of the dried products. The other quality parameters such as, TSS, reducing sugars, total sugars, total solids and titratable acidity of dried products were found to be better as compared to other modes of drying.

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