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Performance Evaluation of a Solar Tunnel Dryer For Around the Year Use

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Abstract
This study was done to evaluate the performance of a walk-in type solar tunnel dryer for around the year use. In the present study, theperformance of solar tunnel dryer was evaluated at no load and at full load conditions. Full loading was done with garlic, chili, fenugreek and aonla candy according to their seasonal availability in Hisar, India. At no load condition, performance was evaluated during three seasonsi.e summer, winter, and autumn. During full load, the dryer reduces the moisture content of garlic from 65% (w.b.) to about 8.5% (w.b.) in 8 days, chilli from 77%(w.b.) to 7% (w.b.) in 7 days, fenugreek from86% (w.b.) to 7.2% (w.b.) in 5 days and aonla candy from 44% (w.b.) to a safe moisture content of 16%(w.b.).The thermal efficiency of thedryer was also measured and was found between 8.89% to 17.63%. A temperature of 15-30 ^{0}C higher than the atmospheric temperature was recorded inside the dryer.Products dried were hygienic and their sensory evaluation showed that they were of good quality and highly acceptable.

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Introduction

Drying is an excellent way to preserve food and open sun drying is the oldest agricultural practice to preserve food[1]. The moisture content in fresh produce is the basic cause for spoilage and if water is removed then the shelf life of production increases. Removal of water results in are duction of weight and volume of the product, thereby reducing the cost and facilitating easy transportation. Drying is a unit operation widely followed under value addition[2,3]. Since drying is a cost-intensive operation, use of solar energy is preferable as it is a non-exhaustive and eco-friendlypractice[4]. Traditional sun drying is the oldest method often resulting in poor quality produce, as the product is not protected against wind, rodents, dust, rain, bird etc also drying process is not controllable requiring more drying space and labor[5,6].Direct sunlight results in loss of color as well as the flavor of the product and it becomes undesirable[7].Solar dryers are the best alternatives

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to traditional drying because mechanical drying is not affordable by small farmers[8,9].

Natural convection solar dryers successfully reduce the post-harvest losses[10]. Natural convection solar tunnel dryer was invented and tested by the Institute for Agricultural Engineering, Hohenheim University, Germany[11]. The same design was also tested by a lot of other researchers in their geographic conditions and found that solar tunnel dryer conserves a lot of energy[12,13]. A little modification was done in the tunnel dryer to minimise the heat losses astested by the Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, (27 420 N, 75 330 E) Rajasthan, India[2]. Large-scale and controlled dryingis possible in asolar tunnel dryer. It is large enough to allow a person to enter and carry out various operations. The orientation of tunnel solar dryer should be in aneast-west direction to minimise the heat losses and ultraviolet stabilized polycarbonate/polyethylene sheet of 200-micron size is mostly used as a cover material[14].Keeping in view of the above-mentioned aspects, this study is done to evaluate the performance of solar tunnel dryer for around the year use for drying of fruits and vegetables.

Material and Method

Raw Material

According to the seasonal availability, four products (garlic, chili, fenugreek leaves and aonla candy) were selected for the drying purpose in a solar tunnel dryer.

Sample Preparation for Drying

Garlic

Freshly harvested of garlic was procured from the university farm of CCSHAU, Hisar during the month of June. The garlic was then cleaned manually and unwanted material like straw and dust were removed. After weighing bulbs were broken into cloves using a garlic bulb breaking machine .The loose 'papery shell" was removed by aspiration.

Chilli

Chillies were cleaned manually and unwanted materials were removed. After cleaning total quantity was graded into three groups according to their condition and color. Starting weight and moisture content of all the samples were recorded One lot of the sample was subjected to chemical treatment by blanching using hot water at 90 ^{0}C for 3 minutes and then cooled in cold water and drained on a perforated tray. The samples were then loaded in solar tunnel dryer for drying.

Fenugreek

Fresh, matured fenugreek was procured from local market of Hisar during the month of January. The fenugreek was cleaned manually after cleaning it was stalked. The weight of the cleaned one and initial moisture content of fenugreek was recorded before drying.

Aonla Candy

The fractionated portions or slices left after making aonlamurabba were used for candy making by soaking in 75% sugar syrup for three days. These slices were procured from market. The sugar treated slices were loaded in solar tunnel dryer for drying.

Drying

After preparation, samples were kept in solar tunnel dryer during the month of their availability. A unique versatile andlow-cost Solar Tunnel Dryer was developed at MPUAT, Udaipur. Realizing the importance of solar tunnel dryer for value addition and processing of products a similar dryer with a floor area of 10m × 3.75m was installed at Hisar to evaluate its performance in ambient conditions of Haryana. It consists of a semi-cylindrical metallic frame covered with UV stabilized transparent polyethylene sheet of 200-micron thickness, five chimneys on the top, two exhaust fan and five vents towards the bottom remove the moist air, insulated wall on north side and the floor was painted black. It consists of 64 trays for loading of material. The average temperature inside the tunnel was 10-20 ^{0}C higher than the ambient temperature. The dimensions and other parameters of solar tunnel dryer are given in table 1. After loading various parameters which were required for analysis and temperature was recorded at 2 h interval during drying.

Performance evaluation of solar tunnel dryer

Performance of the solar tunnel dryer was evaluated at no load and full load condition for garlic, chili, fenugreek and aonla candy. Various parameters were recorded during the process

Table 1: Discription of STD

Parameter	Specifications
Length of solar tunnel dryer	10 m
Width of solar tunnel dryer	3.75 m
Ceiling height	1.98 m
Dimensions of tray	.81 * .73 m2
Flooring height	.19 m

Solar Insolation

solar insolation was measured by using suryamapi in mW/cm^2

Ambient Temperature

it was measured by using mercury thermometer.

Dryer temperature at different points

twelve thermometers were placed at different positions inside tunnel.

Moisture Content

The starting and final moisture content of samples were determined by the AOAC method[15]. About 10 to 20g samples was taken and kept in the oven at 80 °C. Final weight was taken after attaining constant weight and moisture content.

The subsequent moisture content of the samples during the drying period were calculated by weight reduction method after a regular interval of time using the formula:

$$Mt(\%w.b.) = (Wt-Wf)/Wi\times100$$

Here, Mt = Moisture Content at time t
Wt = Weight of sample at time t
Wf = Weight of oven dry sample
Wi = Initial weight of sample

Drying Rate

Drying rate is weight of water removed per unit time by using the formula[16]:

$$dM/dt = M_i\text{-}M_{i+1}/t_i\text{-}t_{i+1}$$

Where,
dM/dt = Drying rate, percent moisture loss per hour
M_i= M.C. (% wb) of sample at time t_i
M_{i+1}= M.C. (% wb) of sample at time t_{i+1}

Thermal Efficiency of STD

Thermal efficiency of the solar tunnel drier was estimated using the formula[17]:

$$\eta th = m \times hfg/A \times I \times 100$$

Where,
ηth = drier thermal efficiency
m = the mass of water evaporated in time
t = (mi - mi) kg
hfg= the latent heat of vaporization of water (kJ/kg)
A = the area of solar tunnel drier in m^2
I = the solar intensity in W/m^2.

Sensory Evaluation

Sensory evaluation of organoleptic properties of dried products was carried out by panel of ten judges of different age group and sex based on '9' point Hedonic scale[18].

Result and discussion

No Load Testing

No load testing was done for finding temperature status at different places in a solar tunnel dryer. The testing on no load conditions of the dryer was done for three different season's summer, rainy and during winter season. Table.2 shows insolation and temperature variation inside and outside the dryer. Mohod *et al.,* (2011)[19] and Singh *et al.,* (2006)[20] reported similar results at no load conditions.

Performance Evaluation at Full Load Conditions

Performance of the solar tunnel dryer was evaluated for the drying of garlic, chili, fenugreek and aonla candy according to their availability. Table 3 gives the details of starting and final moisture content. It took 4-8 days for drying the products. The temperature within the tunnel was always higher than the starting conditions. Fig. 1 shows solar tunnel dryer at full load conditions. The temperature inside the dryer was optimum for drying. The Higher temperature is not good for some food products as Vega-Galvez et al. (2008)[21] and Turhan *et al.,* (1997)[22] suggested that using temperature above 70 ^{0}C for drying results in a dark brown color due non-enzymatic browning reaction for thered pepper. Drying rate versus moisture content during solar tunnel drying of garlic, chilli, fenugreek and aonla candy is shown in Fig. 2. It is evident from the figure that drying rate was higher at higher moisture content and it decreased as moisture content decreased. At the starting stage of drying moisture content was high and more moisture was evaporated from the outer surface. As the drying process continued, the free moisture available on the surface decreased and less evaporation takes place and hence drying rate significantly decreased with drying time as well as moisture content.

The relationship between rate of drying and moisture content gives following regression equations.

Garlic

$y = -0.000x^2 + 0.036x - 0.347$ $R^2 = 0.978$

fenugreek

$y = 2E\text{-}05x^2 + 0.012x + 0.251$ $R^2 = 0.853$

Red Chilli

For grade 1

$y = 0.000x^2 + 0.003x + 0.371$ $R^2 = 0.974$

For grade 2

$y = 0.000x^2 - 0.012x + 0.414$ $R^2 = 0.918$

For grade 3

$y = 0.000x^2 - 0.003x + 0.548$ $R^2 = 0.988$

Aonla candy

$y = -0.002x^2 + 0.151x - 1.649$ $R^2 = 0.963$

In general, it was found that the drying took place in the falling rate period and the constant rate period was absent for all the products. Falling rate period indicates diffusion. Similar conclusions have been reported for drying studies onion slices[23].The coefficient of correlation was more than 0.80 for all the experimental conditions that revealed the good correlation[24].

Sensory Evaluation

The average values of results of sensory evaluation by 30 panelists using 9- point Hedonic scale in

Table 2: Variation of temperature and insolation during different seasons at no load conditions

Month	Ambient temperature ^0C	Temperature inside STD ^0C	Insolation, W/m^2
May (summer)	(29-44)	(34-60)	(440-820)
July (rainy)	(19-33)	(30-50)	(50-620)
December (winter)	(16-29)	(28-48.5)	(80-640)

Table 3: Drying test results in solar tunnel dryer at full load conditions

Month	Product	Initial Moisture content % (w.b)	Final Moisture content % (w.b)	Drying time (days)	Ambient temperature ^0C	Temperaturex inside STD ^0C	Insolation W/m^2
June	Garlic	60- 70	8 - 9	8	(34-44)	(45-62)	(500-990)
October	Chilli	77-79	7	6-7	(28-37)	(37-60)	(280-880)
January	Fenugreek	86	7.2	5	(15-25)	(21-50)	(100-680)
March	Aonla candy	44	16	4	(33-40)	(41-61)	(320-940)

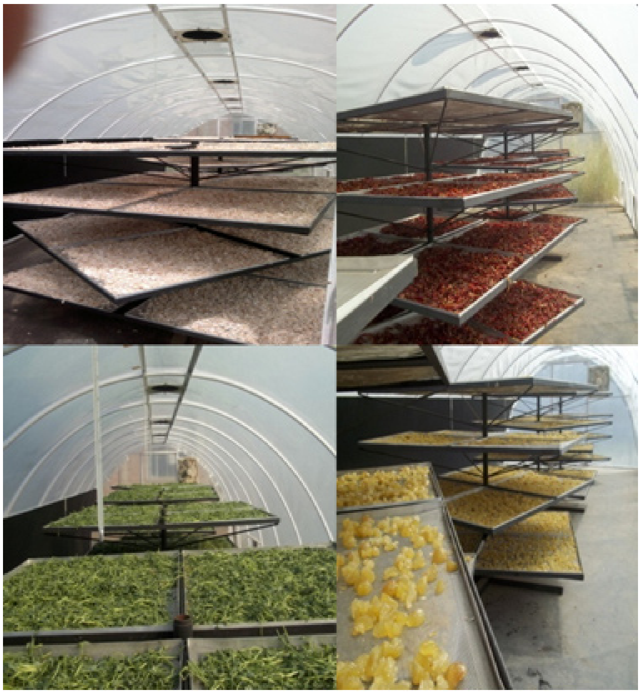

Fig. 1: Solar tunnel dryer at full load conditions when loaded with garlic, chilli, fenugreek and aonla candy

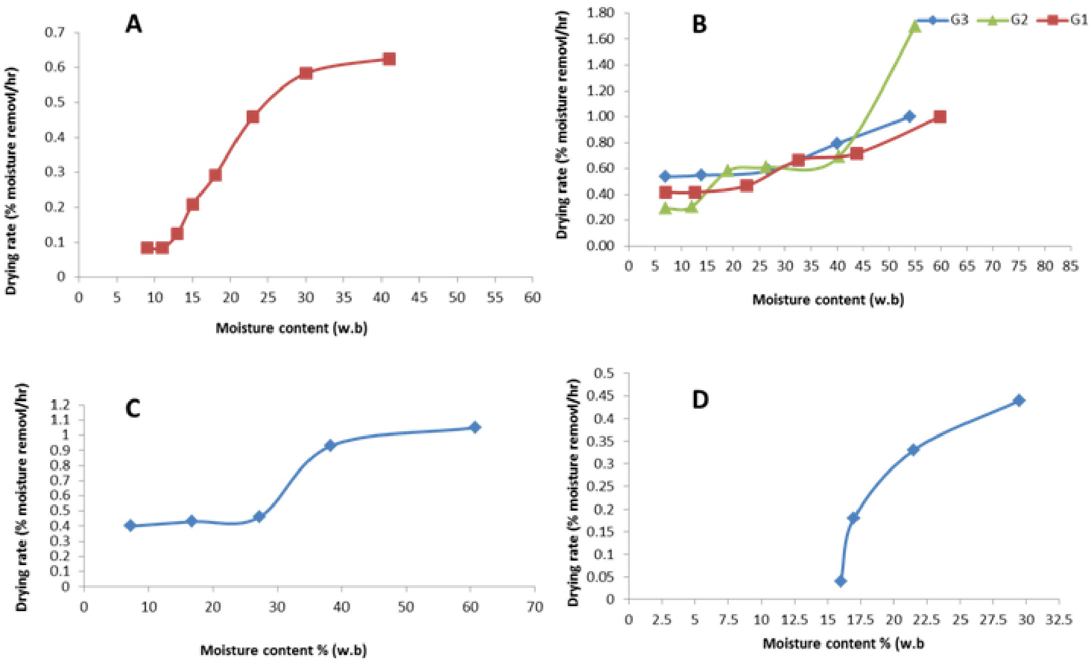

Fig. 2: Drying rate variation with moisture content of (a) garlic, (b) Red Chilli, (c) fenugreek and (d) aonla candy.

terms of color, appearance, flavor, odor, taste and overall acceptance is given in Fig 3. The evaluation shows that the dried products were of good quality and highly acceptable. It is found that chili powder shows highest overall acceptability. Similar results were reported by Janjai *et al.,* (2009)[4], who reported that solar drying increases the overall acceptability and shelf life of products.

Thermal Efficiency of Solar Tunnel Dryer

The overall thermal efficiency of STD was calculated for all the drying cycles. During the initial days of drying the dryer had a higher efficiency as compared to the following days. This was due to starting stage of drying, a higher amount of water was evaporated. Table 4 shows the average thermal efficiency of STD during drying of different products. Chavan *et al.,*(2011)[25] found that overall drying efficiency of the STD is about 19.87% for mackerel drying.

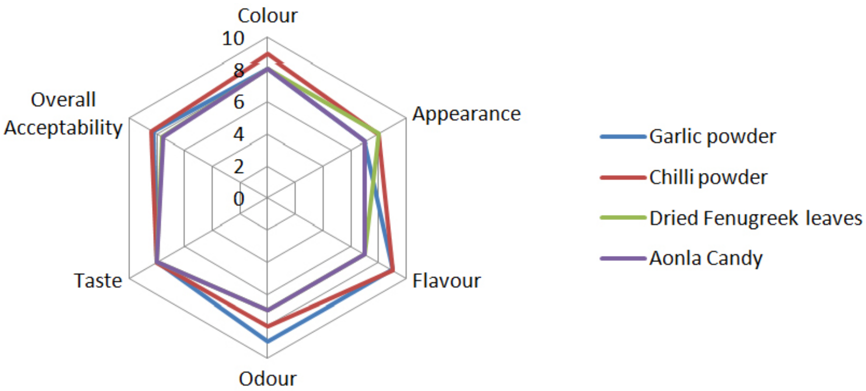

Fig. 3: Radar diagram showing the sensory evaluation of dried products

Table 4: Average thermal efficiency of STD

Product	MW(mass of water evaporated) kg	I (average Insolation) W/m^2	drier thermal efficiency %
Garlic	161	721	13.45
Chilli	112	551	12.25
Fenugreek	81	400	16.27
Aonla candy	196	600	14

Conclusion

Natural convection solar tunnel dryer was capable of drying garlic, chilli, fenugreek and aonla candy from starting moisture content to the final moisture content which is considered to be safe in less than 8 days. Products dried in solar tunnel dryer were hygienic and their sensory evaluation shows that they are of good quality and highly acceptable. The maximum temperature inside the tunnel dryer was 50 ^{0}C while the minimum was 21^{0}C in the typical day of the January against the ambient temperature of 25 ^{0}C and 15 ^{0}C respectively. Average thermal efficiency was found between 8.89% to 17.63%. So, solar tunnel dryer can be utilized for drying highly perishable vegetables and fruits which could increase the income of farmers with little maintenance.

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