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Development and effectiveness of greenhouse type solar dryer for coriander leaves

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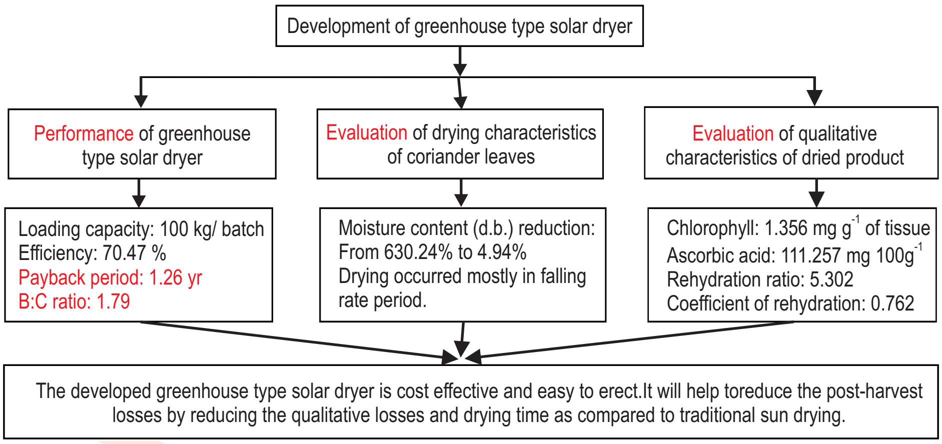
Abstract

Aim: Sun drying system is not able to provide the best drying performance and quality dried produce of leafy vegetables. To facilitate better options to the farmers, this study aims to develop and evaluate a cost-effective greenhouse type solar dryer to improve shelf stability of coriander leaves.

Methodology: A greenhouse type solar dryer (5m x 3m x 2.3m) was developed with the provision of rigid frame, 200 μ UV stabilized LDPE glazing material, solar collector cum drying chamber, inlet air and outlet air openings. The dryer was evaluated for its performance, drying characteristics of coriander leaves and qualitative evaluation of dried product as compared to open sun drying.



Development of greenhouse type solar dryer

Performance of greenhouse type solar dryer

Evaluation of drying characteristics of coriander leaves

Evaluation of qualitative characteristics of dried product

Loading capacity: 100 kg/ batch
Efficiency: 70.47 %
Payback period: 1.26 yr
B:C ratio: 1.79

Moisture content (d.b.) reduction:
From 630.24% to 4.94%
Drying occurred mostly in falling rate period.

Chlorophyll: 1.356 mg g^{-1} of tissue
Ascorbic acid: 111.257 mg $100g^{-1}$
Rehydration ratio: 5.302
Coefficient of rehydration: 0.762

The developed greenhouse type solar dryer is cost effective and easy to erect.It will help toreduce the post-harvest losses by reducing the qualitative losses and drying time as compared to traditional sun drying.

Results: The greenhouse type solar dryer performed well for coriander drying with increased level of temperature inside the dryer (42°C) and 24% reduced drying time as compared to sun drying (29°C).The loading capacity, efficiency, payback period and B:C ratio of the dryer were found to be 100 kg, 70.47 %, 1.26 yr and 1.79, respectively. The drying of coriander leaves occured mostly in falling rate period. Coriander leaves dried under the dryer possessed higher values of chlorophyll content (1.356 mg g^{-1} of tissue), ascorbic acid content (111.257 mg $100g^{-1}$), rehydration ratio (5.302) and coefficient of rehydration (0.762) than sun dried coriander leaves with the respective values of these quality parameters being 1.097 mg g^{-1} of tissue, 62.37 mg $100g^{-1}$, 4.715 and 0.689, respectively.

Interpretation: The developed greenhouse type solar dryer was found to be superior in terms of better retention of chlorophyll and ascorbic acid contents, rehydration ratio and coefficient of rehydration for dried product along with reduced drying time, increased drying rate as compared to sun drying. Therefore, greenhouse type solar dryer could be feasible solution for drying underutilized leafy vegetables so as to get better return.

Key words: Coriander, Drying rate, Efficiency, Greenhouse, Solar drying

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Introduction

Coriander leaves are rich source of L- ascorbic acid, pro-vitamin A, beta carotene, and Vitamin K; in addition, it also constitute nutrients such as carbohydrates, dietary fiber, manganese, iron, magnesium, selenium and potassium (Pirbalouti *et al.,* 2017). Coriander has strong fragrance and health benefits (Venkanna *et al.,* 2019). It helps to counter mouth ulcers, anemia, osteoporosis, diabetes, stomach pain, allergic reactions such as seasonal allergies and rhinitis (Emamghoreishi and Heidari-Hamedani, 2016). The sticky and succulent stems and leaves of coriander are used to impart flavor and garnishing curies and soups. The entire plant when young may also be used for preparing sauces and chutneys. Fresh coriander leaves are available for few months and it cannot be stored for a longer period, but dried coriander leaves can be safely stored for 4 months to make its availability during off season (Singh *et al.,* 2020 a). Peak production of coriander leaves is usually during December – March but due to the perishable nature of coriander leaves there is scarcity in the market during the remaining months (Singh *et al.,* 2020b). The annual production and productivity level of coriander in India is 7.1 lakh metric tons and 1.334 MT ha^{-1}, (Horticultural Statistics at a Glance, 2018).

India contributes approximately 80% of the world's total coriander seed production (Sharma *et al.,* 2014). The highest productivity level of fresh coriander leaves was observed at the tune of 9.26 metric ton ha^{-1} by Rajiv (2019). Because of the purity, freshness, pleasant aroma and longer shelf life of dried coriander leaves, there is a massive demand in the domestic market, restaurants, hotels, households and food and hospitality industries throughout the year. Nowadays, the consumers in cities are pertinent to quality and safety of the food products. Dried coriander leaves create convenience to the fast-food industries and useful for the consumers during lean periods. Drying is heat and mass transfer operation, wherein convection type of heating involves moisture transfer from wet material to heated air, which may be reflected as transport of moisture from the material core to its surface followed by evaporation from the surface of the material and dissipation of water vapor into the bulk of drying air. Solar dryer uses natural or forced movement of heated air.

Solar radiation falling on the transparent covering material and transmitted inside the solar dryer increases the product temperature and the material starts emitting long wavelength radiations that is not allowed to escape out of the dryer. Hence, the temperature above the product inside the drying chamber becomes higher. Drying technique causes transformation of the product, adding value to it and a new opening a new avenue in the market (Akpinar *et al.,* 2003). It also prevents the post-harvest losses of perishable materials, maintains the nutritional status and prevents high prices of vegetables during off season. Solar energy which is available in abundance in used in the process. The earth receives solar energy @ approximately 10^{12} J sec^{-1} for 250-300 clear sunny days and 2300–3200 hrs of sunshine per annum (Yadav, 2015). The simplest and most efficient way to utilize solar energy is to convert it into thermal energy for heating applications. Thus, in a world that is struggling to fight against global warming and other environmental deteriorating factors due to use of conventional fuels for energy, use of solar energy for drying of agricultural produce can prove beneficial for all.

Drying is generally considered as the oldest and commonly used technique for preserving food materials. Open sun drying is a traditional and cheap method of preservation (Rabha *et al.,* 2017), but the drawback of this method is deterioration of crop by ultraviolet rays, dust particles and abiotic factors such as insects, animals, microorganisms which do not meet the international standards. Though sun drying is a popular method of crop drying but it is a slow drying process with chances of mold growth causing deteriorate of dried products (Sagolsem *et al.,* 2021), weather dependent, labor demanded and greatly exposed to possible environmental contaminations (Yadav and Singh, 2013). Solar greenhouse reduces the losses which occur during open sun drying because they work efficiently and reach higher temperatures due to greenhouse effect, and besides the foods are protected (Qiu *et al.,* 2016).

UV solar thermal radiations destroy most of the light sensitive nutrients present in fresh food during drying (George *et al.,* 2015). Solar UV radiations also stimulate the β- carotene oxidation process and are also responsible for the loss of vitamins (Li *et al.,* 2017). Solar greenhouse dryers are framed structure having transparent glazing materials used to reduce the moisture upto safe level by natural convection or forced convection. A solar greenhouse not only attempts to capture maximum solar energy but also minimizes the unwanted thermal exchange between greenhouse and the surroundings in order to maintain desirable temperature. While heating systems based on conventional energy sources may find applications in some locations, the major scope exists for solar greenhouses for farmer's point of view. Drying depends on air temperature, greater the air temperature, faster would be drying.

The most common change that occurs in open sun drying of green vegetables is the loss of chlorophyll and ascorbic acid contents because of direct exposure to the sun and more drying time and therefore, a greenhouse type solar dryer with the provision of UV stabilized covering material, shade net below the cover, air inlets and exhaust systems may play an important role in the reducing the drying period and improving the product quality (Sahdev *et al.,* 2014). Yadav *et al.* (2014) studied the physico-chemical characteristics of dehydrated onion powder and found most acceptable dried product when samples were dried under solar dryer after slicing to 2 mm thickness. Singh *et al.* (2014) and Singh *et al.* (2016) also observed greenhouse type solar dryeras a better option for traditional open sun drying to preserve the color, flavor, taste and overall acceptability of dehydrated amaranth leaves. Some work has been done towards redesigning greenhouses to take full advantage of solar energy for greenhouse heating. The design, development and efficiency of polyhouse dryer has been reviewed by Sangamithra *et al.* (2014) whereas the features and benefits of indirect type solar dryer for agricultural crops has been reviewed by Lingayat *et al.* (2020). Khama *et al.* (2016) classified the solar dryers into active or passive mode. Thamkaew *et al.* (2021) provided an overview of various drying technologies to improve the quality of herbs. Ahamed *et al.* (2019) presented various energy saving techniques to minimize the greenhouse heating cost and highlighted the importance of design parameters (shape, orientation).

The cost of heating represents 70-85% operation cost (Anifantis *et al.,* 2017). To develop an energy-efficient greenhouse solar dryer which involve minimum cost of heating to increase the thermal accumulation inside the dryer, design considerations particularly shape, orientation and glazing materials are important. Ghasemi *et al.* (2016) studied the performance of various greenhouse shapes with respect to consumption of energy and found single span shape as the highest receiver of solar energy. An increased level of solar radiation was observed at the tune of 51.8% in a single span Quonset shape and east-west oriented greenhouse with greenhouse length width ratio greater than one. Ahamed *et al.*, 2018). Mobtaker *et al.* (2019) conducted an experiment on six greenhouse roof shapes and reported 8% higher solar radiation by east-west oriented single span greenhouse. Hempattarasuwan *et al.* (2020) evaluated the performance of parabolic shape solar dryer (6.0m x 8.2m) covered with polycarbonate sheets having concrete floor. Recently, Singh *et al.* (2021) has designed and developed naturally ventilated greenhouse covered with 200µ UV stabilized plastics sheet which can be used as an alternative medium and hi-tech greenhouses.

Heat loss also occurs from greenhouse dryer which needs low cost and easy to install insulating material for the base of drying chamber and to increase thermal accumulation inside dryer. Suitable structural design with the provision of insulated ground floor, inlet/outlet openings and which can be operated without electrical appliances is needed. Such structures might be feasible to the farmers' at large scale. To the best of our knowledge, there is research gap on the need-based study on cost effective greenhouse type solar dryer in view of small and marginal farmers for drying leafy vegetables. Therefore, a study was undertaken with the objective to develop a cost-effective greenhouse type solar dryer and its evaluation with respect to capacity, efficiency, thermal variations, drying characteristics of coriander leaves, quality characteristics of dried coriander leaves and economics.

Materials and Methods

Design and development of greenhouse type solar dryer: Greenhouse type solar dryer GTSD was designed in such a way to arrest maximum solar energy. The system as a whole represents solar collector cum energy storage device. The orientation of GTSD was East-West as it provides higher overall light levels than the North-South direction. Locally available materials were specified in the design to produce cost-effective solar dryer. Solar greenhouse dryers are constructed with rigid load bearing frame and a transparent cover material placed on them which allows short wave solar radiations to enter and is partially opaque to the long wave radiations leading to a greenhouse effect under the dryer. The 200µUV stabilized plastics sheet because of its special characteristics to screen UV solar thermal radiations was selected to cover the greenhouse type solar dryer. Other important considerations *viz.,* shape, air inlet, air outlets, and insulation of the floor of the dryer also play an important role in efficient drying. The base of the floor was made of black painted metallic sheet (upper layer) below which glass wool as insulating material (middle layer) was placed just above the cement concrete floor (bottom layer).

This floor absorbs the maximum possible solar radiation to store more heat.Solar radiation passing through the covering material as well as black painted bottom floor raise the drying temperature inside the dryer. Provision of insect proof UV stabilized plastics net (5" width) on the south wall just above the ground level and throughout the length were made to allow the inlet air flow inside the dryer. Two exhaust outlet pipes (1.5m, L shaped) were fixed just below the top on the north side wall to facilitate the movement of moist air out of the drying chamber. GTSD has been developed to provide dryer capacity of 100 kg fruits and vegetables with multi-layer drying rack system. Considering all these points, a greenhouse type solar dryer having specifications as given in Table 1 was developed at the Horticulture Research Centre, S.V.P. University of Agriculture and Technology, Meerut, India. Different views of greenhouse type solar dryer are shown in Fig. 1.

Performance evaluation of greenhouse type solar dryer: To investigate the performance of greenhouse type solar dryer, fresh coriander leaves (cv. Pant Haritma) obtained from Horticultural Research Centre of S.V.P. University of Agriculture and Technology, Meerut, was used. Before drying, samples were washed in clean running tap water. Roots and undesired materials were removed. Dehydration experiment of washed coriander samples were performed using two methods of drying *viz.,* greenhouse type solar dryer (GTSD) and control *i.e.,* sun drying (SD), with three replications and averages are reported. The samples were spread onto trays in a thin layer at a load of 2 kg m^2 and subjected to drying under GTSD and in SD. Various measuring devices were installed *viz.,* RH/temperature meters to measure air temperatures in the dryer and ambient air, hot wire anemometer (Airflow, model TA5) to measure the air speed inside and outside the dryer, pyranometer (Kipp & Zonen, model CM3) to measure incident solar radiation on top of the roof of the dryer, hygrometer (detensor, model) to measure relative humidity of air.

The weight of coriander leaves samples were recorded using digital electronic balance. The drying process of coriander leaves was started at 10:00 a.m. and continued till 5:00 p.m. Samples of coriander in the dryer were weighed at an interval of 30 min to determine the moisture content. After 5 p.m., the samples were packed in air tight polythene covers and kept

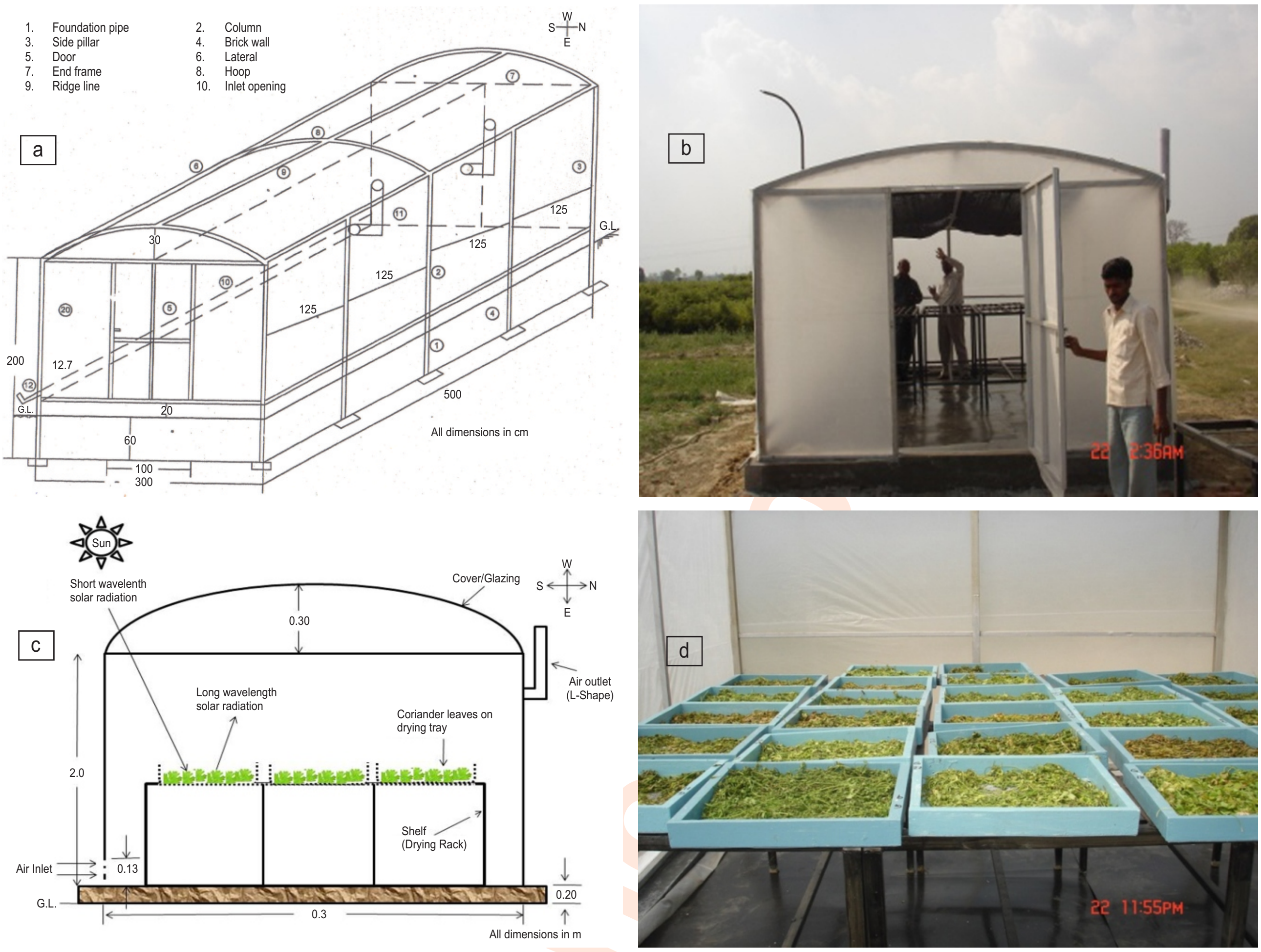

Fig. 1: Different views of greenhouse type solar dryer: (a) CAD of structural frame; (b) Developed structure; (c) Experimental set-up and (d) Experimentation under the dryer).

Table 1: Specification of greenhouse type solar dryer

Parameters	Specification
Dimensions:	Length: 5.0 m, Width: 3.0 m, Side height: 2.0 m, Central height: 2.3 m
Shape	Modified Quonset(single span)
Slope of roof	36.90 from south and north wall
Orientation	East-west direction
Dryer frame	38 mm square MS pipe with paint finish
Glazing material	200 µ UV stabilized LDPE
Floor	Cement concrete floor, insulated with glass wool and covered with black painted iron sheet (22 gauge)
Air inlet opening	0.13 m wide inlet of insect proof net throughout the length on south wall, covered with plastics film with the rolling system
Air outlet opening	L shapechimney (1.5 m length) on north wall
Tray holding frame	Dimension: 2.0 m x 0.7 m x 1.0 m, made of 30 mm square MS pipe, with the provision of 3 steps of racks namely upper, middle and lower
Drying trays	35 cm x 30 cm x 5 cm size wooden frame, perforated stainless steel base
Mode of drying	Natural convection solar drying
Shade system	Provision of black shade net (70%) below the top glazing material. It was fixed on north side which may be opened as per the need.
Inside temperature	May be more than 15 0C above the ambient during summer.

during night. Next day, the samples were spread on the trays in the morning. Drying was continued till the final three readings of weight of coriander leaves remain constant. Drying performance was evaluated in terms of variations in moisture content (MC) and drying rate (DR) with time, and loading capacity (LC_d) and the efficiency (η) of greenhouse type solar dryer using the experimental data. Initial moisture content of the coriander leaves was determined by the method recommended by Ranganna (1995). The weight of the sample was converted to moisture content (MC) on dry basis (% d.b.) by the following standard formula:

$$MC=(Mi-M_d)x100/M_d \qquad \ldots (1)$$

Where, M_i- M_d = mass of moisture evaporated (g)

M_i=mass of samplebefore drying (g)

M_d =mass of sampleafter drying (g)

DR refers to the rate of change of MC (%d.b.) over a particular time interval and it was calculated as the per method suggested by Raol *et al.* (2013):

$$DR = (MC_t- MC_t+\Delta_t)/\Delta t \qquad \ldots (2)$$

Where, MC_t is the moisture content of the product at any time t (% d.b.), $MC_{t+\Delta t}$ the moisture content at time t+Δt (% d.b.) and t the time at any instant (min).

LC_d (kg per batch) was calculated as the ratio of total input energy available (q_{input}, kJ) under the dryer to the energy required for one kg of vegetable ($q_{required}$, kJ kg^{-1}). To estimate the loading capacity of GTSD, the following equation (3) was developed in the current study. Energy required for one kg of vegetables includes both sensible heat of raising the temperature and latent heat of evaporation of water (Pachpinde *et al.,* 2019).

$$LC_d = q_{input}/q_{required} \qquad \ldots.. (3)$$

$$q_{input} = I_a.T_d.T_r.A \qquad \ldots (4)$$

$$q_{required} \text{ is } H_s+ H_l= m.C_p.\Delta t+ m_{ev}.\lambda \qquad \ldots (5)$$

Where, H_s is the sensible heat required to remove the moisture from the vegetable; H_l is latent heat required to remove the moisture from the vegetable; I_a is the solar radiation of ambient (kJ hr^{-1} m^{-2}); T_d is the drying time (hr); T_r is the transparency of the glazing material of the dryer (%); A is the area of drying under the dryer (m^2) m is one kg, mass of vegetable; m_{ev} is the mass of water evaporated from one kg selected vegetable during drying (kg); C_p is the specific heat for coriander leaves= 3.5 kJ kg^{-1} °C (Sabrina *et al.,* 2012); Δt is the difference of initial and final temperature of the vegetable during drying (°C) and λ is the latent heat of vaporization of water (kJ kg^{-1}).

η of greenhouse type solar dryer is defined as the ratio of energy used to evaporate the moisture from the product to the energy supplied to the greenhouse type solar dryer through solar radiations, and it was evaluated using equation (6) (Ayyappan *et al.,* 2015).

$$\eta\,(\%) = M_{ev}.\lambda x\ 100/\ I_a.T_d.A \qquad \ldots (6)$$

Where, M_{ev} is the mass of moisture evaporated from the total mass of coriander leaves to be dried (loading capacity)

$$= LC_d.m_{ev}$$

Analysis of qualitative characteristics of coriander: The quality of coriander was characterized in terms of rehydration ratio (RR) and coefficient of rehydration (CR), chlorophyll content (CC) and ascorbic acid content (AAC) of each sample of coriander leaves dried under GTSD and SD. The methods described by Ranganna (1995) were used for determining of RR, CR and AAC. Rehydration was conducted using one gram of dried sample with soaking period of 5 min. Chlorophyll content was determined by the method described by Arnon (1949).

Statistical Analysis: The experimental data of drying and quality parameters of coriander leaves were statistically and graphically analyzed. Data were subjected to analysis of variance (ANOVA) and analyzed using the method described by Gomez and Gomez (1984).

Results and Discussion

The temperature and relative humidity profiles are shown in Fig. 2 and 3. The ambient (open sun) air temperature increased till 2 p.m. and started declining further. However, under greenhouse type solar dryer, it increased until 3 p.m. and further started decreasing. It is evident from the graph that the temperature and relative humidity profile inside the dryer varied more with the ambient temperature and relative humidity conditions. The highest temperature attained under GTSD was 50.6°C, which was about 17°C higher than the ambient temperature. The average temperature of 42°C was observed inside the dryer as compared to the average ambient temperature of 29°C. This showed an average 45% increase in dryer temperature over the ambient. Drying temperatures of 40°C or above were typically achieved under GTSD from 11:30 to 16:00 hrs.

The increase in temperature under GTSD was made possible due to the combined effect of greenhouse and suitable design of the base of the dryer and glazing materials. Romuli *et al.* (2019) and Chauhan and Kumar (2016) also observed increased temperature of drying air. The present study corroborates with the findings of Alonge *et al.* (2012) who reported that the maximum temperature (51°C) was obtained in direct passive solar dryer as compared to 38°C of ambient temperature. The range of relative humidity was 17% to 63% inside the GTSD as compared to 26% to 49% under SD (Fig. 3). However, average relative humidity inside the GTSD (33%) was less as compared to ambient (37%). During drying process, the drying air picks up moisture from the coriander leaves resulting in decrease in temperature and

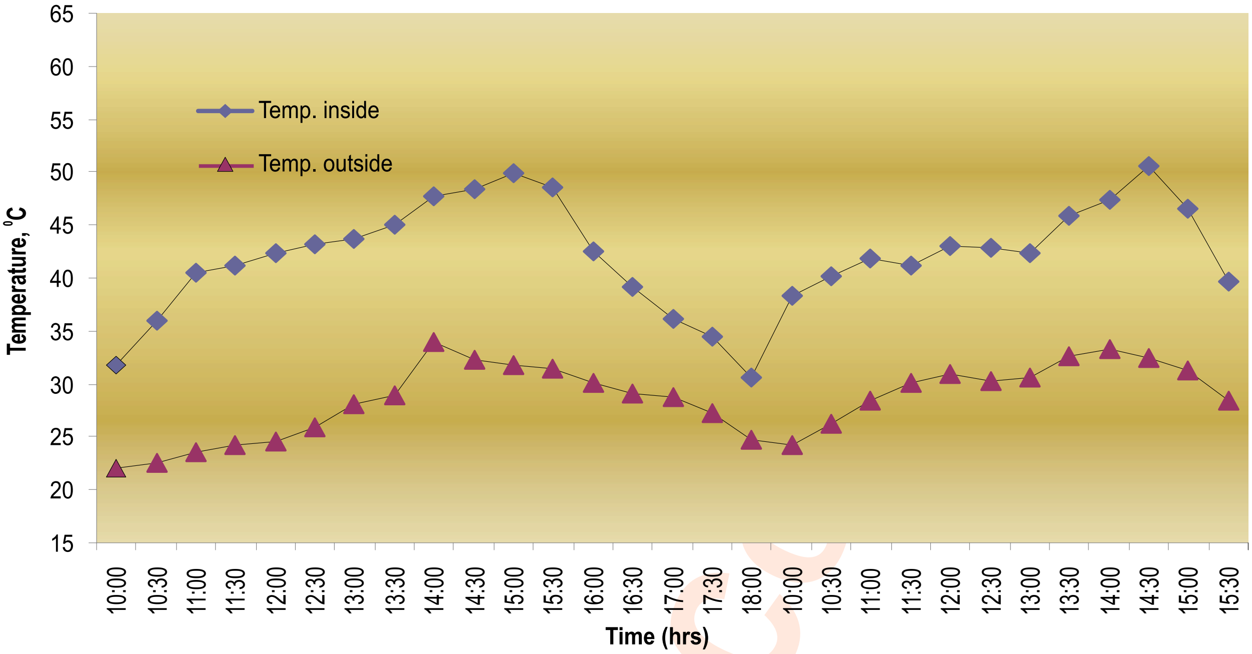

Fig. 2: Time verses temperature graph of inside and outside greenhouse type solar dryer during drying of coriander.

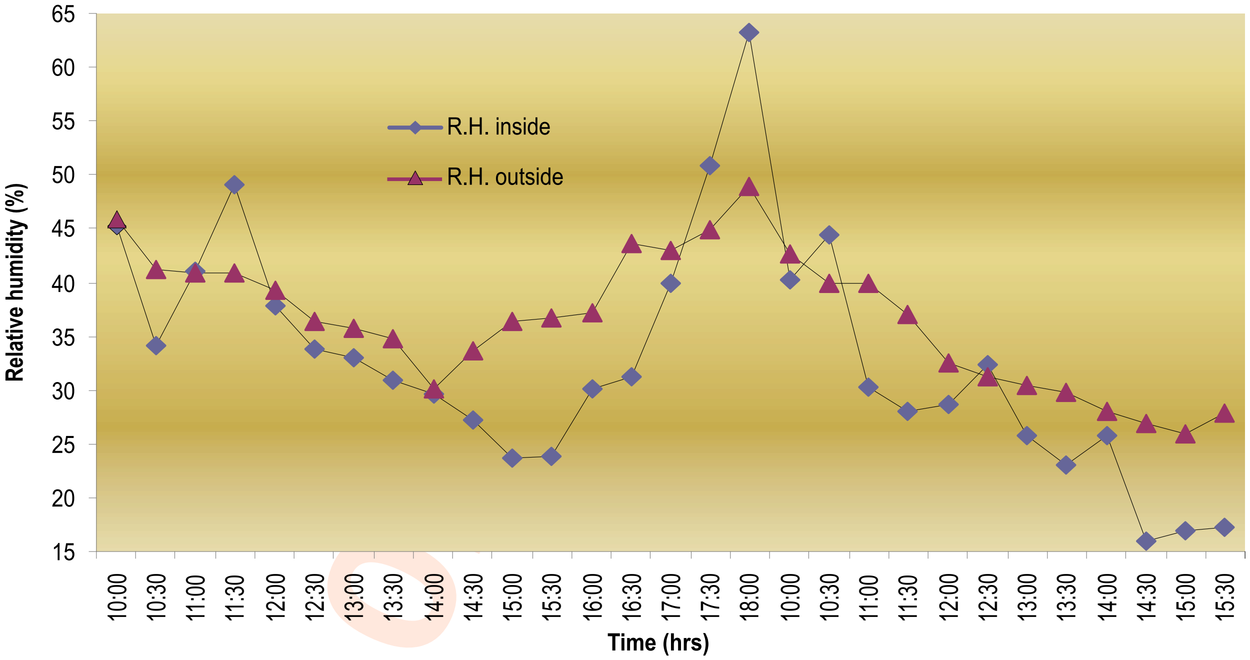

Fig. 3: Time verses relative humidity graph of inside and outside greenhouse type solar dryer during drying of coriander.

increase in relative humidity of the surrounding air. The lower values of relative humidity favor the drying process because of higher potential of air to evaporate the moisture. Vengsungnle *et al.* (2020) reported similar observation. During the experiments, the sky was clear with average radiation values of 840 W m^{-2} and 630 W m^{-2} under the ambient and GTSD, respectively. The average air flow rate inside GTSD through inlet to outlet opening was 0.71 m sec^{-1} during 10:00 a.m. to 6:00 p.m. which accelerates the drying process because when solar radiation is high, the air flow rate from inlet to outlet under GTSD is also high. Inversely, when the radiation is low, the air flow is low (Karwa and Chauhan, 2010).

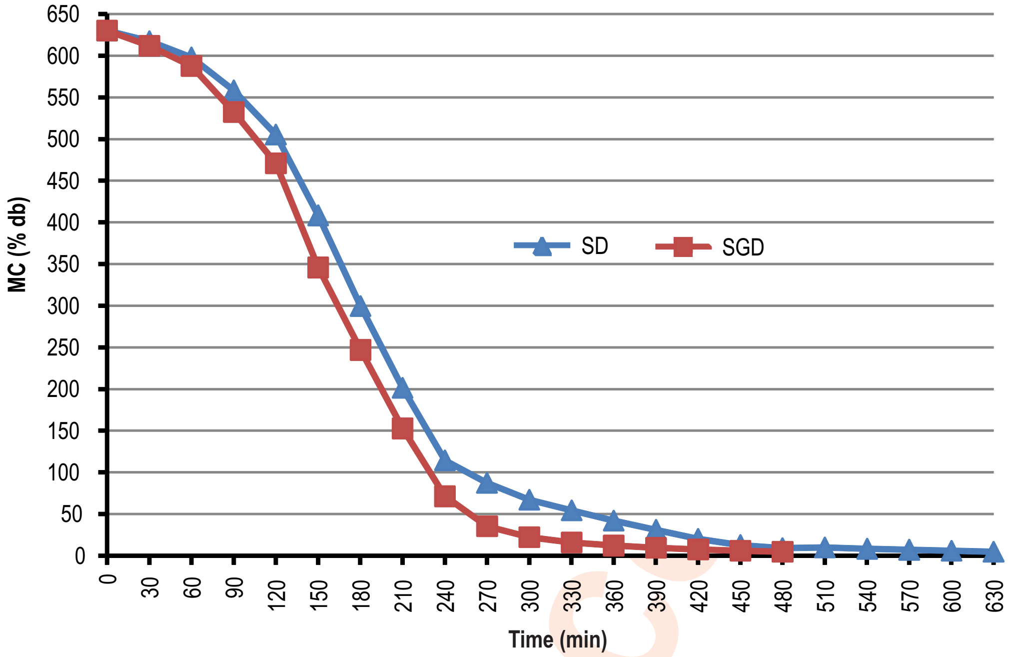

Fig. 4: Time verses moisture content graph of inside and outside greenhouse type solar dryer during drying (SD: Sun Drying, SGD: Solar Greenhouse Drying).

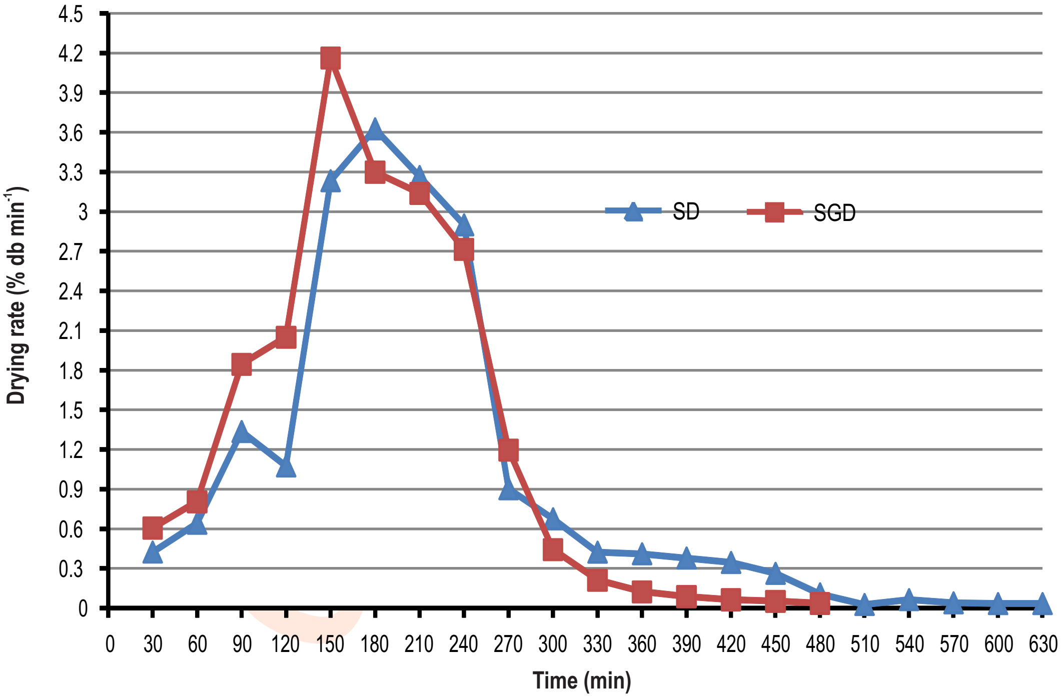

Fig. 5: Time verses drying rate graph of inside and outside greenhouse type solar dryer during drying (SD: Sun Drying, SGD: Solar Greenhouse Drying).

Drying curves *viz.* moisture content verses time and drying rate verses time of coriander leaves inside and outside the solar greenhouse dryer are presented in Fig. 4 and 5, respectively. The initial moisture content of fresh coriander leave prior to drying was 630.24% (d.b.), whereas the final moisture content of the leaves dried under GTSD and SD were 4.94% (d.b.) and 4.98% (d.b.) respectively. The total drying time under GTSD was 8 hr which was 24% less than the time required to dry the material under SD. Cerezal *et al.* (2020) determined the drying time of 10 hr for shredded lettuce leaves under solar dryer assisted with photovoltaic cells at temperature ≤ 52^{0}C and air speed of 1.0 m sec^{-1}. Morad *et al.,* 2017 observed 25% reduction in drying time under solar tunnel greenhouse dryer as compared to regular greenhouse dryer Morad *et al.* (2017). Sacilik *et al.* (2006) also observed 20% less drying time for tomato under solar tunnel greenhouse dryer (4 days) as compared to open sun drying mode for 5 days. Reduction of drying time at the tune of 65% under solar dryer as compared to open sun drying for rose was also observed by Pachpinde *et al.* (2019).

Similar observations to accelerate drying by 30 to 40% compared to conventional sun drying was reported by Singh *et al.* (2018). Moisture content decreased slowly during initial 60 min of drying because of low temperature in the morning, then rapid decrease was noted during 60 to 150 min because of warming of drying environment and further after 150 min, decrease in moisture content slowed down considerably (Fig. 4). Faster drying took place between 60 to 150 min, followed by longer falling rate period. During falling rate period, the material surface was not saturated with water and drying was predominantly through diffusion of moisture from the inner part of the material to the surface. During falling rate period, moisture evaporation rate to the surrounding atmosphere exceeded the moisture diffusion rate from the inner surface to the outer surface of coriander leaves. Omolola *et al.* (2019) and Singh *et al.* (2017) also observed major part of drying in falling rate period on drying the leaves of spider plant and berseem plant. The decrease in drying time with increase in the air temperature was also observed by Ahmad (2013). The drying rate curves (Fig. 5) also showed the accelerated DR during initial phase of drying upto 150 min.

This may be due to the generation of internal heat within the material on exposure to GTSD. Low drying rate during first hour was due to low value of drying air temperature as well as air velocity. As the climate warmed up and drying air temperature attained its maximum value during the hottest part of the day, the drying rate was maximum. Maximum part of drying occurred between 120 min to 300 min and during this period, the drying chamber remained at high temperature under GTSD. After 150 min, drying rate began to decrease (*i.e.* start of falling rate) with decrease in moisture content, signifying that drying of coriander leaves occurred in falling rate period and decreased markedly after 300 min and continued to decrease with the drying time. Darvishi *et al.* (2014) and Garg *et al.* (2014) also reported drying under falling rate period for pepper and pea pods respectively. As normally expected, all these figures (Fig. 4 and 5) show that the design of GTSD improved drying condition mainly due to increased thermal accumulation which resulted in higher drying rates and lower drying time. Ndirangu *et al.* (2020) indicated improved drying conditions of solar energy based greenhouse dryer through higher heat supply for the drying of sweet potatoes, banana and arrow roots. Similar findings were reported by Doymaz, 2004 for carrots and Doymaz, 2005 for okra.

Loading capacity (LC_d) and efficiency (η) of greenhouse type solardryer were evaluated for the coriander leaves considering the values of I_a, T_d, T_r, A, m, C_p, Δt, λ as 3024 kJ hr^{-1} m^{-2}, 8 hr, 0.75, 15 m^2, 1 kg, 3.5 kJ kg^{-1} ^{0}C, 35^{0}C, 2280 kJ kg^{-1} respectively. As the coriander leaves were dried from initial moisture content of 630.24% db to final moisture content of 4.94 % db, the final mass of dried product was calculated as 0.1438 kg (M_d). Therefore, the mass of water evaporated from 1 kg coriander leaves was 0.8562 kg.

The values of LC_d and η was 131 kg and 70.47%. Kadam *et al.* (2011) observed 20.82% thermal efficiency of greenhouse dryer for dehydrating pretreated (NaCl + KMS) onion slices. Similarly, Boonyasri *et al.* (2011), Nayak *et al.* (2011) and Ayyappan (2018) observed 55.7%, 34.2% and 24% greenhouse dryer efficiencies for pork, mint and coconut respectively. The efficiency of GTSD in the present study was observed to be more or less same as those of Chowdhury *et al.* (2011). Benedict *et al.* (2019) designed and developed a solar dryer (325 m^2 floor area) and observed the loading capacity of 2000 kg per batch of wet tomatoes with 30% drying efficiency. Recently, Hempattarasuwan *et al.* (2020) reported the loading capacity of 100-200 kg for fruits or vegetables of a parabolic greenhouse type solar dryer (49.2 m^2 floor area).

The maximum greenhouse drying efficiency of 65.30% was observed by Chowdhury *et al.* (2011) for jackfruit leather. Elkhadraoui *et al.* (2015) observed loading capacity of 80 kg (pepper) and 130 kg (grapes) in a greenhouse having solar collector. The average values of rehydration characteristics of dried coriander leaves *viz.* rehydration ratio and coefficient of rehydration, and the bio-chemical properties of fresh and dried coriander leave *viz.* CC and AAC are presented in Table 2. The

Table 2: Qualitative parameters of fresh and dried coriander leaves

Parameters	Fresh coriander	Dehydrated coriander		Percentage loss	
		GTSD	SD	GTSD	SD
Moisture content (% db)	630.24±3.12^a	4.94±0.50^b	4.977±0.61^c	99.22	99.21
Chlorophyll content (mg^{-1} g of tissue)	1.689±0.02^a	1.356±0.13^b	1.097±0.70^c	19.74	35.06
Ascorbic acid content (mg 100g^{-1})	253.1±1.73^a	111.257±2.31^b	62.37±1.98^c	56.042	75.358
Rehydration ratio		5.302±0.45^b	4.715±0.30^c	11.07*	
Coefficient of rehydration		0.762±0.05^b	0.689±0.04^c	9.58*	

* % age lower values as compared to the sample dried under sun; Values are means± standard deviations, values in row with different letter superscripts are significantly different at p<0.05.

Table 3: Computation of payback period and benefit cost ratio of GTSD

Item	Values
Fresh coriander	Rs. 50/- per kg
Dried coriander leaves	Rs. 1000/- per kg
Dried product net weight	0.11 kg per kg of fresh coriander leaves
Drying batch	100 batch
Capacity of the GTSD	100 kg/ batch
Capital cost of the dryer	Rs. 50,500/-
Life of the dryer	15 yrs
Depreciation	Rs. 50,50/-
Cost of maintenance	Rs. 1000/-
Labor cost, @ Rs. 380/- per labor: 1.5 x 100 x 380	57,000/-
Cost of fresh coriander: 100 x 100 x 50	Rs. 5,00,000/-
Total income (revenue): 100 x 100 x 0.11 x 1000	Rs. 11,00,000/-
Total investment cost	Rs. 6,13,550/-
Net income per year	Rs. 4,86,450/-
Payback period	1.26 yr
B:C ratio	1.79

perusal of data shows significant ($p< 0.05$) variation in the values of qualitative parameters of dried produce between GTSD and SD methods. In both the drying methods, the moisture removal was upto 99.2%. No significant difference in moisture content of dried produce was obtained between GTSD and SD methods. The rehydration ratio and coefficient of rehydration decreased for dried coriander leaves under SD as compared to GTSD. The values of RR and CR for the samples dried under sun were 11.07 % and 9.58 % lower as compared to the samples dried under GTSD. Due to lesser duration of drying time, thermal disruption of cell organization was less in coriander samples dried under GTSD as compared to SD, therefore, rehydration ratio and coefficient of rehydration values were more under GTSD as compared to SD. This result was in confirmation as observed by Singh *et al.* (2020 b). They observed better retention of rehydration ratio and coefficient of rehydration for dehydrated coriander leaves under solar dryer.

The initial chlorophyll content and ascorbic acid content values of coriander leaves before drying were 1.689 mg g^{-1} tissue and 253.1 mg 100g^{-1}, respectively. The highest and lowest values of chlorophyll content were found as 1.356 mg g^{-1} tissue and 1.097 mg g^{-1} tissue for the coriander leaves dried under GTSD and SD respectively. The loss in chlorophyll content compared to fresh sample was more under SD condition (35.06%) as compared to GTSD condition (19.74%). Sun drying, resulted in significant loss of pigments, leading to more oxidation of carotene. Lakshmi *et al.* (2000) reported the loss of β-carotene in the range of 24-40 % in sun- dried leaves and 6-25% from sun dried and cabinet dried green leafy vegetables. Flowers dried in hybrid solar dryer were found to be superior in terms of color and carotenoid content (Pachpinde *et al.,* 2019). Yilmaz and Alibas (2017) also observed higher chlorophyll content and green color for microwave- dried coriander leaves as compared to open sun-dried samples.

Ascorbic acid content loss was higher in samples dried under SD (75%) due to exposure for longer time. Though the drying temperature was less under SD, but, however, due to long drying time, the activities of ascorbic acid oxidizing enzymes increased which destroyed ascorbic acid. On the other hand, high temperature and short drying time under GTSD resulted into less loss of AAC (56%) as compared to SD. This indicates that the drying temperature in combination with drying time is an important factor to decide the quality characteristics. Under GTSD, direct exposure of coriander leaves to solar radiation was avoided due to the provision of UV stabilized plastics sheet as well as black shade net below the top glazing material, which reduced the loss of AAC in dried samples. Lakshmi *et al.* (2000) reported 69-85% AAC loss in green leafy vegetables due to sun drying (35–40^{0}C) and 51 to 63% due to cabinet drying (60– 70^{0}C). Mehta *et al.* (2017) also emphasized the effectiveness of solar drying of vegetables for retaining better quality (vitamin C and chlorophyll content) as compared to open sun drying. GTSD minimized the qualitative losses during drying as it enclosed with UV treated covering material which screened out the thermal UV radiations (Chauhan and Kumar, 2016).

Therefore, GTSD showed better suitability in retaining the quality of dried produce. Cost economics of GTSD was evaluated with respect to annual revenues, payback period and benefit cost (B:C) ratio as per the procedure used by Boonyasri *et al.* (2011) and Singh *et al.* (2009). Table 3 shows the economic evaluation of GTSD. Few considerations were made to calculate the economic analysis viz. effective space for drying of samples inside the GTSD as 80% of the floor area, therefore, capacity of the dryer was taken as 0.80x 131 kg (104.8 kg), say 100 kg per batch, and drying time of 8 to 10 hr per batch. Based on the cost price of coriander leaves during their flush and information available in the market, cost of fresh produce as well as dried produce were taken.

The payback period and B:C ratio values of 1.26 year and 1.79 were observed (Table 3) which clearly indicates that GTSD is worth making the investment. Boonyasri *et al.* (2011) and Ayyappan S. (2018) also observed 1.15 yr and 3.3 yr of payback periods of solar greenhouse dryers for pork and coconut drying. Similarly, Elkhadraoui *et al.* (2015) found payback period of 1.17 yr for red pepper under greenhouse drying with 20 yr of estimated life of the greenhouse dryer. Vijayan *et al.* (2020) reported the payback period of 2.1 yrs for indirect solar dryer of expected life of 3.5 years. Kiburi *et al.* (2020) reported the payback period of less than one year with four years life span of the supplemented heating-based greenhouse dryer. Krungkaew *et al.* (2020) mentioned that the enterprises with annual revenues higher than their investment costs of solar dryers would have positive net present value (NPV) indicating that the investment was attractive. In the present study, the annual revenue was Rs. 11,00,000/- higher than the investment costs (Rs. 6,13,550/-). Therefore, it can be concluded that the developed GTSD using locally purchased materials is proved to be effective with respect to technical, cost and environmental issues.

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Add-on Information

Authors' contribution: S. K. Singh: Designed the experiment, performed the experiment, wrote the paper; **Samsher, B. R. Singh:** Analysed and interpreted the date; **R. S. Sengar:** Searched literature; **P. Kumar:** Contributed chemicals and tools.

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