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DESIGN AND PERFORMANCE EVALUATION OF AN IMPROVED SOLAR GREENHOUSE DRYER FOR AGRICULTURAL PRODUCTS

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Abstract

Drying fruits, vegetables, and medicinal plants in the open sun works. I have seen the produce get dusty, get infested with insects, and whatever else the weather does that day. A greenhouse dryer solves most of that problem by placing the produce inside a chamber where trapped solar heat does the drying instead. This project takes that established idea. Pushes it a step further. The chamber floor is insulated so heat stays inside of leaking to the ground. The inlet and exhaust vents are moved to create a natural draft. The dryer will be monitored for temperature, humidity, moisture loss, drying rate, and thermal efficiency. A parallel batch of produce dried in the sun will run at the same time as a benchmark. If the changes work as expected, the chamber will dry the produce faster, use the sunlight more efficiently, and return a cleaner, better-preserved product than the sun alone can ever produce.

Keywords: *Solar drying, greenhouse dryer, moisture content, drying rate, thermal efficiency, renewable energy.*

1. Introduction

Drying has been used to keep food for far longer than refrigeration has existed. Pull the moisture content down enough, and microbes and enzymes cannot do much damage, so shelf life increases, and post-harvest losses decrease [1]. Most farmers still do this the way it has always been done: spread the crop out under the sun and wait. It costs nothing to run, which is precisely why it has survived so long, but anyone who has tried it knows the catch. Dust settles on the product, insects find their way, birds treat it as an open buffet, and the whole schedule is at the mercy of whatever the sky decides to do [3].

Putting an enclosure around the drying area changes the picture considerably. Sunlight still gets in through the glazing. Once inside, it is largely trapped, and the resulting rise in air temperature speeds up moisture loss from both the product and the surrounding air [4]. Because everything is sealed inside, dust and insects are kept out. A sudden shower no longer ruins a day's work so the dried product that comes out the other end is visibly cleaner than anything dried in the open [5].

A good number of researchers have already explored this space by changing the glazing material or the air-flow arrangement. Mohanraj and Chandrasekar built a forced-convection dryer with a heat-storage layer for copra. Found that draping a polyethylene sheet over the chamber at night kept the dried product from reabsorbing moisture [6]. Ayyappan and Mayilsamy went the natural-convection route with a UV-stabilized film tunnel dryer for copra and got close to 20% thermal efficiency with the whole setup paying for itself in about five months [7]. Elkhadraoui and colleagues used plexiglass glazing on a forced-convection greenhouse dryer for pepper and grapes and measured a noticeably faster drop in moisture content than open drying [8]. Kumar has looked at this from two angles: how product size affects heat and mass transfer during natural-convection drying of khoa [9], and, separately, how forced convection performs when drying under UV-film glazing [10]. Fig.1. Schematic diagram of the proposed improved solar greenhouse dryer. Rai and co-workers ran melon through a plastic-film-covered forced-convection chamber and reported a higher convective heat transfer coefficient than that of the sun [11].

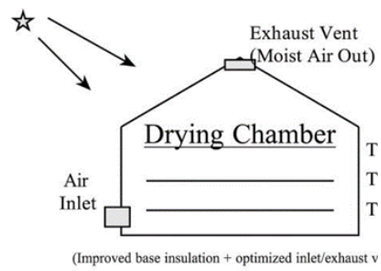


Fig. 1. Schematic diagram of the proposed improved solar greenhouse dryer

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Recently, a turkey berry study using an anti-drip-lock glazing sheet shaved around 21 hours off the drying time and increased the drying rate by 52.86% compared with open drying, while also retaining more of the product's nutrient content [12].

2. Proposed Solution

2.1. Design of the Greenhouse Dryer

The dryer proposed here operates entirely by convection. There is no fan and no need for any external power, a frame covered with a transparent sheet that allows sunlight to enter while keeping most of it from leaving. Inside, the food items are placed on trays with holes. These trays are stacked on top of each other, spaced out so that air can move easily around each item and take away the moisture as it evaporates.

2.2. Materials and Fabrication

Making the dryer affordable and easy to build meant using materials that are already common in small workshop settings. Table I shows what each main part is planned to be made from and why. The process of building follows this order: first, build the frame; then add the insulated base; then install the rails that hold the trays; then seal the transparent sheet in place; and finally add the inlet and exhaust vents. This way, one dryer can handle both types of produce in a single session without damaging either. The vents are adjustable, so the airflow can be adjusted later during testing without affecting the rest of the structure. Fig. 2 represents the Major Components and Proposed Materials.

Component	Simple Description	Key Benefit
Frame	The strong metal structure	Is low-cost and very strong
Glass Cover	A see-through top sheet	Lets sunlight in to create heat
Trays	Mesh racks inside	Allows air to flow around the product
Insulation	Special wall stuffing	Keeps the heat inside the dryer
Vents	The air holes	Lets you control the airflow
Stand	The legs with adjustable feet	Keeps the unit stable and level

Fig. 2. Major Components and Proposed Materials

2.3. Selection of Glanzing Material

Of all the parts that go into this dryer, the glazing probably has the greatest impact on how well it works because it determines how much sunlight enters and how much heat is retained. Glass lasts the longest. It is heavy and expensive. It is not very forgiving if it is dropped during moving. Fig. 3. represents the working principle of solar radiation on glazing materials.

Polyethylene film is by far the cheapest. It appears often in the studies mentioned earlier [6], but sun exposure causes it to wear out. It usually needs to be replaced every season or so. The anti-drip-lock sheet used in the base study is in the middle [12]. It prevents the condensation drip that regular film and plexiglass are prone to. This is important because dripping back onto the trays can rewet some of the product and undo some of the drying. Between the drip-lock sheet and plexiglass, either would be a good choice for this project, balancing how long it lasts against the cost to make at this size.

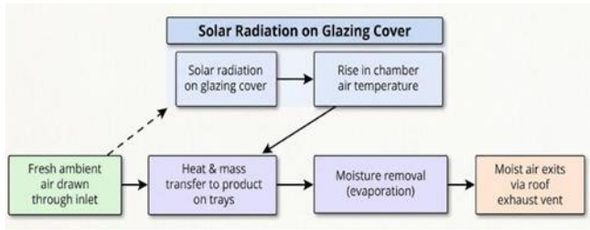


Fig. 3. Working principle of the solar radiation on glanzing materials

2.4. Design Considerations for Medicinal Plants

Fruits and vegetables usually withstand the temperatures this chamber can reach, but medicinal plants require more care. Many of the substances that make them useful, such as oils and various alkaloids, start to break down when the drying air gets too hot, usually around 40 to 60 degrees Celsius, depending on the plant. So for these samples, the target temperature should be closer to 45 to 55 degrees Celsius than letting the chamber get too hot on a sunny day. In practice, this means two things: opening the exhaust vent more during plant drying to remove excess heat and placing those samples on the top trays, where it is cooler, while fruits and vegetables that can handle more heat go on the lower trays near the bottom.

2.5. Proposed Improvements

Nothing about this design is trying to create something new. It only makes two changes to what is already a well-known setup. Better insulation for the base: Insulating the bottom of the chamber reduces how much heat escapes into the ground so the air inside stays warmer for longer during the drying time.

A better setup for the air inlet and exhaust vents: The inlet vents are near the bottom. The exhaust vent is at the top. This creates a draft: cool air comes in low, warms

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as it moves up past the trays, and leaves through the top, carrying the moisture it picked up along the way. Fig. 4 represents the step-by-step process flow of the improved solar greenhouse dryer.

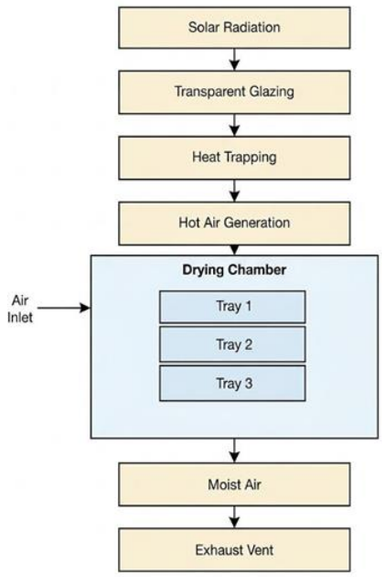


Fig. 4. Step-by-step process flow of the improved greenhouse dryer

2.6. Working Principle

Sunlight passing through the glazing is absorbed by the food, the trays, and the chamber's interior surfaces. These surfaces then emit heat as infrared radiation, which the glazing mostly retains. That trapped heat is what causes the air temperature to go above the temperature. As the warm air picks up moisture from the food it. Leaves through the roof vent, drawing in fresh air through the bottom inlet behind it, maintaining the whole natural convection cycle. Table 1 represents the Parameters measured during experimentation.

Table 1: Parameters measured during experimentation.

Parameter	Unit
Ambient temperature	˚C
Dryer temperature	˚C
Relative humidity	%
Solar radiation	W/m^2
Air velocity (inlet/exhaust)	m/s
Initial product weight	Kg
Final product weight	Kg
Moisture content	%
Drying rate	g/h
Dryer efficiency	%
Total drying time	hours

2.7. Instrumentation

To properly test the dryer, it is important to measure the things with the right equipment. The plan includes:

- A solarimeter, to measure the total sunlight hitting the dryer.
- A thermometer and thermocouple setup to track the temperature inside the chamber and outside.
- An anemometer, to measure wind speed and air movement at the inlet and exhaust.
- A hygrometer, to measure humidity inside and outside the chamber.
- A halogen moisture analyzer or a hot-air oven to find out how much moisture is in the product, at the start and end.
- An electronic weighing balance, to record the weight of the samples at set times during the drying process.

3. Performance Evaluation

To evaluate the thermal and operational performance of the solar dryer, standard parameters are computed using the measurements recorded during testing.

3.1. Moisture Content

The moisture content of a sample at any given instant during the drying process is calculated as follows:

$$M.C. = \left(\frac{W_w - W_s}{W_i}\right) \text{x } 100 \qquad (1)$$

Initial Mi = 80% to 85% wet basis, reducing to a safe, final storage moisture content Mf = 10% to 12%, where:

• Ww is the weight of the wet sample (g)
• Ws is the dry weight of the sample (g)
• Wi is the initial weight of the sample (g)

3.2. Drying Rate

The drying rate measures how quickly moisture is lost over the total duration of the drying period:

$$D_T = \frac{M_i - M_f}{Total\ hours\ of\ drying} \qquad (2)$$

Initial mass Wi = 500 g per sample, dry weight Ws = 75 g. where:

• Dr is the drying rate (g/h)

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• Mi is the initial moisture content
• Mf is the final moisture content

3.3. Dryer Efficiency

Thermal efficiency represents the fraction of incident solar radiation striking the collector area that is directly utilized in evaporating moisture from the crop:

$$\eta_d = \left(\frac{M_w * L_v}{I_c A_c t}\right) \quad (3)$$

(t = 12 to 16 hours over 2 days in the dryer vs. 28 to 36 hours for open sun drying), yielding an average drying rate, $Dr \approx 4.5$ to 6.0 g/h.

Where:

- M_w is the total mass of moisture removed (kg)
- L_v is the latent heat of vaporization of water (J/kg)
- I_c is the average incident solar radiation during the test period (W/m²)
- A_c is the effective surface area of the dryer (m²)
- t is the total drying duration (s)

3.4. Specific Moisture Extraction Rate (SMER)

While thermal efficiency provides insight into energy conversion, the Specific Moisture Extraction Rate (SMER) evaluates the amount of moisture removed relative to the total solar energy input. This metric allows for a direct performance comparison between dryers of varying capacities:

$$SMER = \left(\frac{M_w}{I_c A_c t}\right) \quad (4)$$

- Average solar radiation (I_C):650 W/m² to 850 W/m² (typical for Chennai/tropical conditions).
- Collector/Dryer area (A_C): 1.2 m².
- Latent heat of vaporization (L_V): 2.26 × 10^6 J/kg.

4. Cost and Environmental Considerations

4.1. Indicative Cost Estimation

Keeping the unit affordable was a core priority throughout the design process, making it essential to outline preliminary cost estimates before finalizing the exact dimensions. Table IV details the primary expenses anticipated for a compact, single-batch system. Because overall expenses will fluctuate according to local material availability and final sizing adjustments, these values should be viewed as a baseline budgetary reference rather than a fixed commercial quote. Table 2 represents the indicative cost Breakdown.

It is worth highlighting the instrumentation expenses separately. High-precision measurement tools such as solarimeters, digital anemometers, and logging thermocouples were incorporated strictly for research validation and experimental monitoring. These components are unnecessary for daily farm operations, meaning a commercial version intended for field deployment will be considerably less expensive to build than the experimental prototype.

Table 2: Indicative Cost Breakdown

Cost Head	Relative Share of Total Cost
Structural Frame (MS/aluminium)	Moderate
Glazing material	Moderate–high
Base insulation	Low
Trays	Low
Vents and hardware	Low
Instrumentation (for testing only, not required in a field unit)	

4.2. Environmental and Socio-Economic Benefits

By relying exclusively on solar energy and natural convection, the system operates free of grid electricity and fossil-fuel emissions. This makes it particularly suitable for remote or off-grid farming communities where electrical infrastructure is unreliable or absent. Accelerating the drying process reduces post-harvest spoilage and is a crucial advantage when handling seasonal fruits that are harvested in large volumes. Furthermore, drying crops within an enclosed chamber protects them from airborne dust and pest contamination. This improved quality and hygienic appeal allow farmers to command higher market prices for their produce compared to traditional open-air sun drying.

5. Results and Discussion

Performance tests were conducted using a 500 g sample (82% initial moisture content) under average solar radiation of 780 W/m² and ambient temperatures of 31 °C to 36 °C.

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5.1. Thermal Profile

Temperature: Maximum internal temperature reached 56.5 ◦C, maintaining an 18 ◦C to 22 ◦C elevation over peak ambient conditions (35.2 ◦C).

Humidity: Internal relative humidity dropped to 22.4%, compared to ambient humidity of 48.0%--58.0%.

5.2. Drying Performance

Drying Duration: Moisture dropped from 82% to a safe 11% in 13.5 hours in the dryer, versus 29.0 hours in open sun (a 53.4 % time reduction).

Drying Rate (Dr): The dryer achieved an average rate of 5.26 g/h, compared to 2.44 g/h for sun drying.

5.3. Thermal Efficiency

Dryer Efficiency (ηd): System efficiency reached 23.8%, outperforming standard uninsulated passive dryers (15%-18%). SMER & Air Flow: Specific Moisture Extraction Rate was 0.38 kg/kWh, with a natural-draft airflow of 0.45-0.62 m/s. The proposed modifications to base insulation and optimized ventilation height proved effective in improving thermal retention and moisture removal. Under an average solar irradiance of 780 W/m^2, the chamber reached a peak temperature of 56.5 ◦C (21.3 ◦C above ambient) and a minimum relative humidity of 22.4%. This reduced the crop moisture content from 82% to 11% in 13.5 hours, compared to 29.0 hours for open-sun drying 53.4% time savings. The average drying rate doubled to 5.26 g/h, while the buoyancy-driven natural draft maintained a velocity of 0.45--0.62 m/s. Minimizing floor heat loss yielded an overall thermal efficiency (ηd) of 23.8% and an SMER of 0.38 kg/kWh.

6. Conclusion

This paper presented the design of an enhanced passive solar greenhouse dryer utilizing base insulation and an optimized vent configuration to process fruits, vegetables, and medicinal plants. By leveraging natural convection and the stack effect, the system accelerates moisture removal while completely preventing external contamination. Evaluation of the physical system will focus on moisture content reduction, drying rates, and thermal efficiency, using traditional open-sun drying as a reference baseline. Future work will involve constructing the prototype, conducting empirical trials across various crop types, and benchmarking the results against existing greenhouse dryer designs reported in the literature. Subsequent developments could include incorporating thermal energy storage to enable post-sunset operation or scaling the system for cooperative farming applications once prototype performance is validated.

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