Design, Fabrication, and Performance Evaluation of a Low-Cost Double-Glazed Solar Tomato Dryer

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***Abstract*—Post-harvest losses of tomato remain a major contributor to food waste and food insecurity in Nigeria, where inadequate storage and reliance on open-air sun drying leave the crop vulnerable to spoilage and contamination. This paper presents the design, fabrication, and performance evaluation of a low-cost, double-glazed solar tomato dryer intended for small-scale farmers. The system couples a flat-plate solar box collector, tilted at sixteen point seven degrees, to a ventilated drying chamber holding three mesh trays. Governing equations were used to size the drying chamber, collector, and vent, and a black-coated aluminium absorber with a double glazing arrangement was adopted to limit heat loss. The fabricated dryer was tested with sliced tomato samples under natural sunlight. Collector temperatures reached a peak of eighty four point one degrees Celsius in the early afternoon, and the sample mass fell from seven point ninety seven grams to one point thirty grams within about six hours, corresponding to a drying efficiency of eighty three point six eight percent. The complete unit was fabricated entirely from locally available materials. The results confirm that a simple double-glazed solar dryer can reduce tomato moisture content quickly and affordably, offering a practical, sustainable route to reducing post-harvest tomato losses in Nigeria and similar high-insolation regions.**

***Index Terms*—solar dryer, tomato drying, post-harvest loss, renewable energy, double glazing, food preservation**

I. Introduction

Food waste occurs at every stage of the supply chain and is estimated at 1.3 billion tonnes globally each year [1], costing an estimated 2.6 trillion USD annually [2] while thousands go hungry. Tomato is among the most perishable of the vegetables grown for mass consumption; with an initial moisture content of about 93–95%, it is highly susceptible to microbial spoilage, bruising, and rapid post-harvest decay.

In Nigeria, tomato production is concentrated in the northern states, which supply roughly 98% of the tomatoes consumed nationally, yet inadequate storage and transport infrastructure mean that a large share of this harvest is lost before it reaches the market or the consumer [3]. Nigeria's Ministry of Agriculture and Rural Development has estimated that around 700,000 tonnes of tomato rot as waste every year [4], and post-harvest losses of harvested tomato generally are reported to reach 40–60% owing to spoilage, poor storage, and inefficient drying [5].

Tomato spoilage is driven by three interacting factors: environmental exposure (heat and humidity accelerate over-ripening), physical damage (bruises and cuts provide entry points for microorganisms), and microbial growth on the fruit surface once handling or storage conditions allow bacteria, yeasts, or moulds to establish.

Drying interrupts this last pathway directly, since lowering the moisture content of the fruit removes the water activity that spoilage organisms require to multiply [6], which is why dehydration remains one of the oldest and most reliable methods of extending the shelf life of perishable produce.

Tomato waste carries economic, environmental, and social costs: it represents lost income for farmers and traders, generates methane and other pollutants as it decomposes, and worsens food insecurity in regions where supply is already limited [3], [4]. One long-established remedy is to dry the tomato, either for direct storage or for conversion into powder, since removing the bulk of the moisture supresses microbial growth and greatly reduces weight and volume for transport [7], [8].

Reducing this waste through accessible preservation methods is widely regarded as crucial to improving food security and encouraging sustainable agricultural practice in Nigeria [9], [10]. Open-air sun drying, the method most accessible to small-scale farmers, is slow, weather-dependent, and leaves the product exposed to dust, insects, and contamination. Solar dryers address these weaknesses by enclosing the product and using a collector to raise the drying-air temperature above ambient, which shortens drying time and improves hygiene and product quality relative to open sun drying [11], [12], [13].

Nigeria is one of the largest tomato producers in Africa,

with an estimated annual output of about 2.3 million tonnes, ranking 14th globally and accounting for roughly 65% of West African and 10.8% of African production [14], [15]. Despite this scale, the country still imports significant quantities of processed tomato because inadequate processing facilities, poor transport infrastructure, and recurring disease outbreaks such as the tomato leaf miner (*Tuta absoluta*) [16] translate high production into high post-harvest loss.

Tomato waste imposes costs beyond the farm gate: spoiled produce decomposing in the open releases methane and other pollutants, lost volumes reduce farmer income and depress the wider agricultural economy, and the resulting scarcity drives up prices in tomato-deficient regions of the country. Contaminated or spoiled tomatoes can also harbour pathogens such as *Salmonella* and *E. coli* [17], posing a direct public-health risk in areas with limited healthcare access. Together, these consequences make tomato preservation both an economic and a public-health priority, and not merely a matter of convenience.

Oyerinde and Braimah [18] fabricated a hybrid solar food dehydrator from locally sourced materials that raised the drying-cabinet temperature well above ambient for several hours after solar noon.

Olaniyan and Lawal [19] developed a simple solar maize dryer with emphasis on improved airflow, while Bala and Mondol [20] demonstrated the effectiveness of an indirect solar tunnel dryer for fish. These and related studies show that even simple, single-glazed solar collectors can meaningfully shorten drying times, but they also point to three recurring limitations: single-glazed collectors suffer significant heat loss and lower attainable temperatures under fluctuating weather [21]; poor airflow management often produces uneven drying between trays [22]; and many designs rely on relatively costly or scarce materials, limiting adoption in resource-constrained settings [23]. There remains, in particular, limited published work on solar dryers that are deliberately designed around the climate, material availability, and cost constraints of Nigerian tomato farmers.

The aim of this work is therefore to design, fabricate, and evaluate a solar tomato dryer that is inexpensive, uses regionally available materials, and remains effective under Nigerian solar conditions.

The specific objectives are (i) to design a solar tomato dryer, (ii) to construct the dryer from durable, low-cost materials, and (iii) to test and evaluate its drying performance. The remainder of this paper presents the design methodology and governing equations , the fabrication procedure and experimental method, and the performance results and efficiency of the fabricated unit , before concluding with recommendations for further improvement.

II. Design and Fabrication Methodology

A. System Description and Working Principle

The dryer is a solar hot-box system comprising a rectangular flat-plate solar box collector coupled to a ventilated drying chamber (Fig. 1). The collector is tilted at 16.7° to the horizontal, close to Bauchi's latitude (≈10.3°N) with additional inclination for adequate rainwater run-off and self-cleaning of the glazing — consistent with common practice for fixed solar collectors at low latitudes.



Fig. 1. CAD rendering of the solar tomato dryer, showing the tilted box collector and the drying chamber with chimney vent.

Solar radiation passes through a double-glazed transparent cover and is absorbed by a black-coated aluminium sheet, converting roughly 90% of the incident radiation into heat. As the air within the collector warms, it becomes less dense and rises by natural convection, drawing fresh air in through an inlet aperture and pushing heated air through an outlet aperture into the drying chamber. This continuous, self-induced airflow passes over tomato slices spread on wire-mesh trays, carrying away the evaporated moisture and exiting through a roof-mounted chimney vent. The drying chamber accommodates three trays, together holding 500 g to 2 kg of fresh tomato per batch.

Moisture removal within the chamber follows the same evaporative-cooling process that governs any convective drying system. As heated air passes over the moist tomato surface, water evaporates from the surface and absorbs latent heat from the surrounding air, so the exposed surface cools toward a value close to the wet-bulb temperature of the drying air. While free moisture remains on the surface, the rate of evaporation, and hence the local cooling effect, stays roughly constant; as drying proceeds and the surface moisture is depleted, moisture must diffuse from the interior of the slice to the surface before it can evaporate, so the drying rate slows and the surface temperature rises back toward the dry-bulb temperature of the surrounding air.

This behaviour is consistent with the temperature and mass-loss trends recorded during testing (Section III), where the rate of mass loss was not uniform across the six-hour period.

Two transparent glass sheets, separated by a 0.127 m air gap, form the collector cover. Compared with a single glazing layer, this arrangement reduces conductive, convective, and radiative heat loss from the absorber, sustains higher internal temperatures, and improves the durability of the collector [24]. The absorber is a 0.5 mm black-coated aluminium sheet

chosen for its high thermal conductivity and low emissivity [25], while polyethylene foam insulates the collector base and sides against heat loss.

Relative to a conventional single-glazed, shallow-bed collector, three modifications were adopted: double glazing to curb heat loss, teak wood in place of softer, less weather-resistant timbers for the frame, and an increased collector depth to lengthen the air path and residence time over the absorber. Together these changes were intended to raise the attainable drying-air temperature without adding moving parts, keeping the dryer simple to operate and maintain while remaining affordable to fabricate.

B. Design Considerations

Three considerations governed the design. First, thermal performance: every practical collector must be efficient, long-lasting, and economical to build, install, and maintain, which in turn requires a high absorption rate for solar radiation, effective insulation to retain heat, and an orientation and tilt angle that maximise solar exposure.

Second, drying-chamber airflow: the chamber must provide sufficient ventilation to remove moisture-laden air without being oversized relative to the drying load, since an oversized chamber is slower to heat and wastes collected heat on empty volume.

Third, material durability and maintenance: all exposed materials must withstand outdoor exposure to sun, wind, and occasional rain with minimal upkeep, and the chamber must be easy to clean between batches to discourage mould and bacterial growth that would otherwise compromise the quality of the dried product [26].

Across all three considerations, the guiding constraint was to offer a good balance between performance and cost, so that the finished dryer would represent value for the investment made rather than performance at any price.

C. Design Calculations

The fundamental measure of collector performance is its thermal efficiency, defined as the ratio of the useful heat delivered to the drying air to the solar energy incident on the collector surface.

The dimensions of the collector and drying chamber, the required ventilation, and the expected drying rate were each sized using standard heat- and mass-transfer relations so that the fabricated system would approach this ideal as closely as practicable within the material and cost constraints of the project.

The drying chamber area A_{dc} was obtained from its length L and width W,

$$A_{dc} = L \times W, \tag{1}$$

and its volume V_{dc} from the chamber height H_{dc},

$$V_{dc} = A_{dc} \times H_{dc}. \tag{2}$$

TABLE I
NOMENCLATURE

Symbol	Description (unit)
A_{dc}	Drying chamber floor area (m^2)
V_{dc}	Drying chamber volume (m^3)
L, W, H_{dc}	Chamber length, width, height (m)
m_{dr}	Average drying rate (m^2/h)
M_w	Mass of moisture to be removed (g)
t_d	Assumed daily drying time (h)
ρ_a	Density of the drying air (kg/m^3)
p	Absolute air pressure (Pa)
$R_{specific}$	Specific gas constant for dry air
T_a	Absolute drying-air temperature (K)
A_v	Required air-vent area (m^2)
V_w	Local design wind speed (m/s)
V_Q	Volumetric air flow rate (m^3/h)
m_a	Mass flow rate of moist air (kg/h)
P_I	Solar power received by collector (W)
L_R, W_R	Collector length, width (m)
n	Number of collectors
M_i, M_f	Initial, final sample mass (g)

The average drying rate m_{dr} was estimated from the mass of moisture to be removed, M_w, over the assumed daily drying time t_d [27],

$$m_{dr} = \frac{M_w}{t_d}. \tag{3}$$

The density of the drying air, ρ_a, was found from the ideal gas law using the absolute pressure p, the specific gas constant for dry air $R_{specific}$, and the absolute drying-air temperature T_a [28],

$$\rho_a = \frac{p}{R_{specific}\, T_a}. \tag{4}$$

The required air-vent area A_v was sized from the chamber volume and the local wind speed V_w [29],

$$A_v = \frac{V_{dc}}{V_w}, \tag{5}$$

and the volumetric air flow rate V_Q needed to complete drying within t_d was [29]

$$V_Q = \frac{V_{dc}}{t_d}. \tag{6}$$

The corresponding mass flow rate of moist air, m_a, followed from [29]

$$m_a = \rho_a \times V_Q. \tag{7}$$

The solar power collected, P_I, was estimated from the collector length L_R, width W_R, the number of collectors n, and the terrestrial peak irradiance of 1000 W/m^2 [30],

$$P_I = (L_R \times W_R \times 1000)\, n. \tag{8}$$

Finally, the moisture content removed and the drying efficiency were evaluated from the initial and final sample masses, M_i and M_f,

$$\text{Efficiency}(\%) = \frac{M_i - M_f}{M_i} \times 100. \tag{9}$$

Applying (1)–(8) to the chosen chamber dimensions ($L = 0.63$ m, $W = 0.53$ m, $H_{dc} = 0.89$ m), an assumed daily

TABLE II
COMPUTED DESIGN PARAMETERS

Parameter	Symbol	Value
Drying chamber area	A_{dc}	0.33 m^2
Drying chamber volume	V_{dc}	0.29 m^3
Average drying rate	m_{dr}	0.047 m^2/h
Density of drying air	ρ_a	1.277 kg/m^3
Air vent area	A_v	0.16 m^2
Volumetric air flow rate	V_Q	0.041 m^3/h
Mass flow rate of moist air	m_a	0.053 kg/h
Solar power received	P_I	588 W/m^2

TABLE III
MATERIAL SELECTION SUMMARY

Component	Material	Primary reason
Frame, chamber walls and trays	Teak wood	Durable, weather- and pest-resistant, low upkeep
Absorber plate	Black-coated aluminium sheet	High conductivity, high solar absorption
Cover (glazing)	Glass sheets (double layer)	Transparent, insulating air gap reduces heat loss
Vent / chimney	Mild steel	Durable, structurally stable under heat
Collector insulation	Polyethylene foam	Low thermal conductivity, moisture resistant

drying time of $t_d = 7$ h, a drying-air temperature of $40°$C, and a design wind speed of $V_w = 1.8$ m/s yields the values summarised in Table II.

D. Material Selection

Materials were chosen to balance durability, thermal performance, and cost, as summarised in Table III. Teak wood was used throughout the frame, drying chamber walls, and trays for its resistance to decay, insects, and moisture, while requiring little maintenance.

A black-coated aluminium sheet served as the absorber for its high thermal conductivity and low reflectivity, and ordinary glass sheets provided the double glazing. Mild steel was used for the vent and chimney, and polyethylene foam insulated the collector against heat loss.

E. Fabrication

The collector box (1.095 m $\times$ 0.51 m $\times$ 0.305 m) was cut from 0.0015 m thick teak wood and assembled with screws. A 0.35 m $\times$ 0.16 m inlet aperture was cut at the front and a 0.44 m $\times$ 0.29 m outlet aperture at the rear to feed the drying chamber.

The black-coated aluminium absorber was fitted along the base and sides, and the collector cavity was insulated with polyethylene foam before the two glass layers (0.94 m $\times$ 0.46 m and 1.095 m $\times$ 0.51 m, each 0.004 m thick, separated by a 0.127 m gap) were fitted over the top (Fig. 2).

The drying chamber (0.89 m $\times$ 0.63 m $\times$ 0.53 m) was likewise built from teak wood, with three evenly spaced horizontal supports, 0.013 m apart, carrying removable stainless-steel mesh trays that allow air to circulate between them (Fig. 3). Every external joint and unintended opening around the assembly, other than the single air vent, was sealed to prevent unwanted heat loss from the drying chamber.



(a) (b) (c)

Fig. 2. Solar box collector during fabrication: (a) teak-wood collector box, (b) black-coated aluminium absorber fitted along the base, (c) the double glazing viewed from inside the box, with insulating gravel packed beneath the absorber bed.



Fig. 3. Drying chamber frame with the three stacked mesh trays installed.

Beyond material choice, several practical factors shaped the build: the frame dimensions were kept small enough for one person to reposition the unit rather than leaving it as a fixed installation; components were cut with precision hand and power tools to keep joints tight and the assembly square; joints were secured with wood glue and screws rather than glue alone, for long-term structural integrity; and every seam other than the designed air vent was sealed to limit uncontrolled heat loss.

Exposed screw heads and sharp edges were finished flush to avoid injury during loading and unloading of trays.

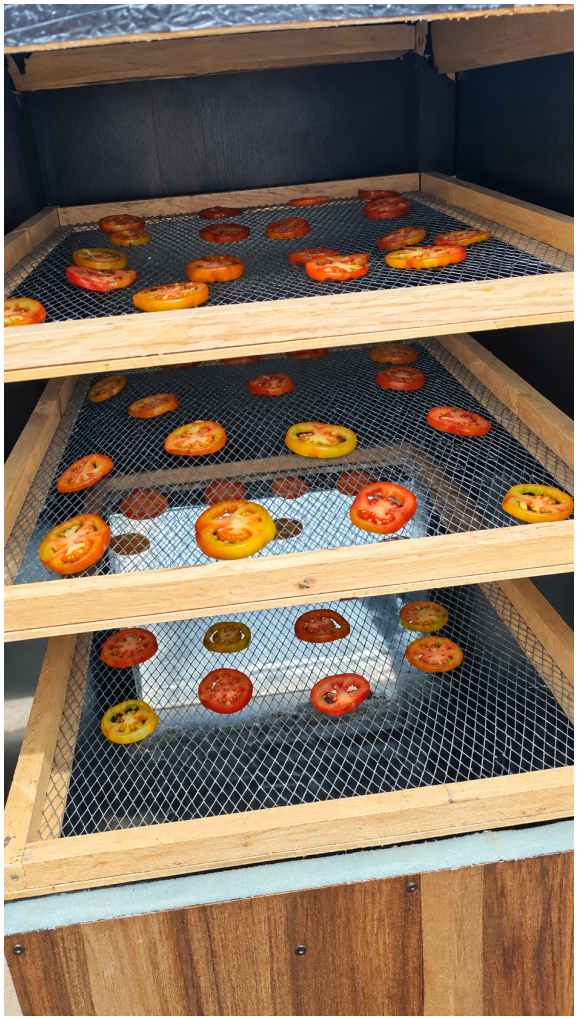


Fig. 4. Sliced tomato samples loaded onto the wire-mesh trays before testing.



Fig. 5. The fabricated solar tomato dryer under test, showing the double-glazed collector and drying-chamber housing.

F. Experimental Procedure

The assembled dryer (Fig. 5) was placed in an unshaded, open outdoor location for testing. Ripe tomatoes obtained from a local market were washed, sliced to approximately 6 mm thickness, and their initial mass recorded on a digital scale before being loaded onto the wire-mesh trays (Fig. 4).

At one-hour intervals from 10:30 h to 16:30 h, the sample mass was re-weighed, and the temperature of the collector, the upper tray, and the lower tray was recorded with a thermocouple. Moisture content loss was then computed from the successive mass readings using (9).

III. Results and Discussion

A. Design Specifications

The final dimensions of the fabricated components, listed in Table IV, closely follow the values obtained from the design calculations in Section II.

TABLE IV
Design Specifications of the Fabricated Dryer

Component	Qty	L (m)	W (m)	H (m)
Solar collector	1	1.095	0.51	0.305
Drying chamber	1	0.63	0.53	0.89
Drying tray	3	0.57	0.445	0.02
Chimney (H; dia.)	1	–		0.305; 0.089

B. Drying Performance

The sample mass, the mass of water removed, and the corresponding moisture-content loss at each measurement interval are recorded in Table V. Fig. 6 plots the same mass data over the six-hour test. The mass fell steadily from 7.97 g at 10:30 h to 1.30 g at 16:30 h. The fastest moisture loss occurred between 14:30 h and 15:30 h, when 2.06 g of water was removed; the slowest loss occurred in the mid-morning, when only 1.2 g was removed between 10:30 h and 11:30 h owing to lower ambient temperature and less intense solar radiation during that time.

The corresponding temperature record is shown in Fig. 7. The collector temperature rose from 63.7°C at 10:30 h to a

TABLE V
MASS AND MOISTURE-CONTENT LOSS DURING DRYING

Time (h)	Mass (g)	Water removed (g)	Moisture loss (%)
10:30	7.97	–	–
11:30	6.77	1.20	17.73
12:30	5.82	0.95	16.32
13:30	4.48	1.34	29.91
14:30	4.34	0.14	3.23
15:30	2.28	2.06	90.35
16:30	1.30	0.98	75.38

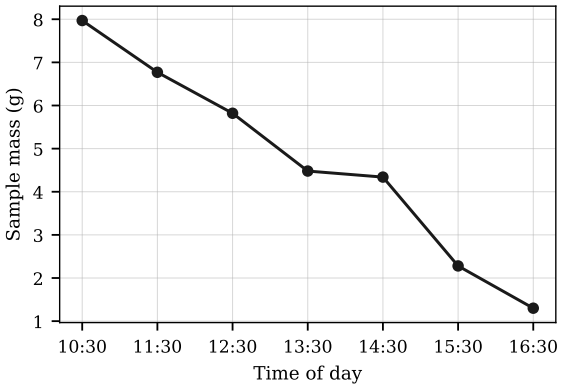


Fig. 6. Tomato sample mass during the drying test.

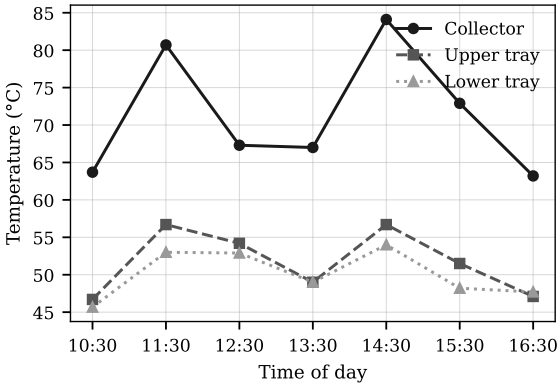


Fig. 7. Temperature of the collector, upper tray, and lower tray during the drying test.



Fig. 8. Tomato samples after approximately seven hours of drying, showing the visibly dried, shrunken slices.

peak of 84.1°C at 14:30 h before falling toward the end of the day.

The upper and lower trays followed the same trend at consistently lower temperatures, reaching a maximum of 56.7°C and 54.0°C respectively, also at 14:30 h.

The upper tray was consistently warmer than the lower tray, most likely because of heat lost during transfer from the collector down through the chamber; the largest gap between the two trays, 3.3°C, occurred at 15:30 h. Despite this gradient, both trays remained warm enough to sustain effective drying throughout the test.

Overall, moisture loss tracked the collector temperature closely, and the dryer was most effective in the early afternoon (13:30–15:30 h), when solar intensity, and therefore collector and tray temperature, were highest.

C. Efficiency of the Dryer

Using (9) with the initial sample mass of 7.97 g and the final mass of 1.30 g after six hours of drying,

$$\text{Efficiency}(\%) = \frac{7.97 - 1.30}{7.97} \times 100 = 83.68\%. \qquad (10)$$

This efficiency reflects the combined performance of the collector and the drying chamber and indicates that the double-glazed design converts and retains a substantial share of the incident solar energy for moisture removal.

It should be read as an overall mass-based drying efficiency rather than a strict thermal efficiency, since it is computed directly from the sample mass loss rather than from a full energy balance on the collector; nonetheless, it provides a practical, repeatable indicator of how effectively a given batch of tomato is dried within a working day, which is the quantity of greatest interest to a farmer alongside protection from dust and adverse environmental factors in deciding between this dryer and open-air sun drying.

The visual condition of the tomato samples after approximately seven hours of drying is shown in Fig. 8, confirming that the measured mass loss corresponds to a visibly and consistently dried product across the tray.

D. Comparison with Related Work

The peak collector temperature obtained here, 84.1°C, is consistent with the elevated cabinet temperatures reported for other low-cost Nigerian solar dehydrators, such as the hybrid dryer of Oyerinde and Braimah [18], and exceeds the 70°C operating range reported for comparable batch-type collectors [11], which supports the choice of double glazing over the single-glazed designs more commonly reported in the literature [19], [20].

The measured drying efficiency of 83.68% likewise compares favourably with simple solar dryers evaluated under similar tropical conditions [13], suggesting that the combination of double glazing, a black-coated absorber, and an increased collector depth is an effective, low-complexity route to improving performance without resorting to fan-assisted or hybrid designs.

At the same time, the temperature gradient observed between the upper and lower trays reflects a limitation common to natural-convection dryers generally [22], reinforcing the case for the forced-airflow improvement recommended in Section IV.

IV. Conclusion

A low-cost, double-glazed solar tomato dryer was designed, fabricated, and evaluated for use by small-scale farmers in Nigeria. Trapping solar heat between two glass layers reduced heat loss from the collector and sustained collector temperatures above 63°C throughout the six-hour test, peaking at 84.1°C in the early afternoon. Under these conditions, the sample mass fell from 7.97 g to 1.30 g, giving a drying efficiency of 83.68%, and the entire unit was fabricated entirely from locally available materials.

These results indicate that a simple double-glazed collector, sized using standard heat- and mass-transfer relations, can dry tomato slices quickly enough to offer small-scale farmers a practical alternative to open-air sun drying, with attendant benefits for food security and reduced post-harvest waste.

Three improvements are recommended for future work. First, a small fan could be added to supplement the natural convective airflow, particularly to reduce the temperature gradient observed between the upper and lower trays. Second, the design could be scaled up, or built as a modular unit, to process larger batches without loss of drying efficiency. Third, replacing the flat absorber with a corrugated-sheet absorber may improve solar absorption and heat distribution, further shortening drying time.

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