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A Comparison of Hot Dry and Transitional Season Solar Drying with A Modified V-Corrugated Solar Air Heater

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Abstract

The thermal performance of solar air heaters can be significantly enhanced by changing the shape of the absorber plate, which increases heat transfer surface area and airflow turbulence. This study investigates the seasonal drying performance of a modified V-corrugated solar air heater that uses natural convection for tomato drying in Kano, Nigeria. Experiments were carried out throughout the transitional season (October-November 2019) and the hot dry season (April-May 2021), using ASHRAE 93-2003 testing procedures. The system includes a V-corrugated aluminium absorber panel, an enclosed drying chamber with three trays, and a chimney to improve buoyancy-driven airflow. The results revealed a maximum drying efficiency of 54.66% during the transitional season and shorter drying periods of 10-12 hours during the hot dry season, compared to 16-22 hours in the transitional months. The moisture level fell from 95.65% to 10% across all trials. Higher sun irradiance, decreased relative humidity, and elevated ambient temperatures during the hot dry season considerably improved the drying performance. The redesigned absorber design improved heat transfer and lowered drying time by 70-85% compared to open-sun drying. The technology provides an economical and sustainable post-harvest preservation solution for rural and off-grid areas.

Keywords: v-corrugated absorber plate; solar drying; solar air heaters; open sun drying; solar powered solution

HIGHLIGHTS

- ✓ A redesigned V-corrugated absorber plate increases heat transfer area and turbulence, yielding a maximum drying efficiency of 54.66% for tomato slices.
- ✓ Drying time during hot dry season (10 h) is nearly 50% shorter than during transitional season (22 h).
- ✓ The enclosed system reduces drying time by 70–85% compared to open-sun drying, while improving product hygiene and colour retention.
- ✓ The passive, natural-convection design is robust, user-friendly and ideal for off-grid rural communities.
- ✓ This solar-powered solution reduces dependence on fossil fuels and provides an affordable, environmentally friendly alternative for year-round post-harvest preservation.

1. INTRODUCTION

Sun drying is a viable and economical method to preserve agricultural products, particularly in tropical locations with high sun irradiance. Enclosed solar dryers outperform typical open sun drying in terms of temperature control, pollutant mitigation, improved product quality, and reduced drying time [1, 2]. These benefits have made solar drying a more appealing option for decreasing post-harvest losses in developing countries [3, 4].

Among numerous improvement tactics, altering the absorber plate design in solar air heaters has proven to be quite effective for enhancing thermal efficiency by increasing heat transfer surface area and producing airflow turbulence. Corrugated and roughened absorber surfaces, such as V grooves, ribs, and artificial roughness elements, reduce laminar airflow and increase convective heat transfer [5,6]. Numerical and experimental investigations have repeatedly demonstrated that such surface alterations can increase thermal efficiency by 30-50% over flat plate designs [7, 8].

Solar drying has been frequently used to preserve agricultural items with high moisture content, such as tomatoes, which degrade quickly. Indirect solar dryers with thermal storage increase drying stability and energy efficiency [9], but climate-specific dryer designs show a significant sensitivity of drying kinetics to ambient circumstances [10,11]. Nonetheless, most accessible research focuses on forced convection systems or short-term performance evaluations.

The effectiveness of solar dryers varies seasonally, and this is especially true in tropical regions with natural convection. Drying rate and moisture diffusion are directly impacted by changes in ambient temperature, relative humidity, and solar radiation intensity between the dry and transitional seasons [12–14].

Nevertheless, there is a dearth of experimental data comparing seasonal drying performance utilising improved absorber plate topologies.

Northern Nigeria is a perfect natural laboratory for assessing seasonal performance since it has distinct hot, dry, and transitional seasons. Optimising system design and operation in rural locations requires an understanding of how climate fluctuations impact solar dryer efficiency.

Therefore, this study aims to:

1. Evaluate the drying efficiency and time of a modified V corrugated solar air heater in Kano, Nigeria, using natural convection during hot dry and transition seasons.
2. Evaluate the impact of seasonal environmental factors (solar radiation, temperature, humidity) on tomato drying kinetics.
3. Evaluate the effectiveness of a low-cost passive system for year-round tomato drying in semi-arid locations.

As shown in Figure 1, this study shows how well a modified V-corrugated solar air heater can dry tomatoes under hot, dry, and transitional seasonal circumstances in northern Nigeria.

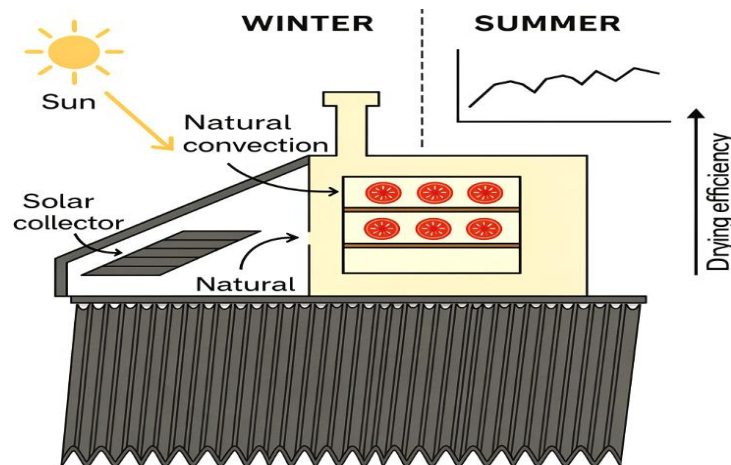


Figure 1 schematic representation of sun drying efficiency in both summer and winter using a modified V-corrugated solar air heater.

2. LITERATURE REVIEW

A low-cost, sustainable technique for post-harvest agricultural product preservation, solar drying has been well studied, especially in tropical and semi-arid areas. Indirect solar dryers are better

than open sun drying because they minimise microbial contamination, enhance product quality, and reduce drying periods [1, 3, 4]. They do this by separating the collector from the drying chamber.

2.1 Absorber Plate Modifications

A popular method for improving thermal performance in solar air heaters is the use of corrugated or ribbed absorber plates, which increase heat transfer surface area and create turbulence.

In their numerical study, Abedalh and Mohammed [5] found that V-grooved corrugated absorber plates had 30–50% higher thermal efficiency than flat plates. Triangular corrugated absorbers under jet impingement were experimentally tested by Kumar et al. [7], who obtained a 47.3% thermal efficiency. In their investigation of semi-circular transverse rib roughness on aluminium absorbers, Assaye et al. [6] found a thermal efficiency improvement of more than 35%. A 48% increase in thermal efficiency was recorded by Sharma and Singh [8] when they employed delta wing turbulators in a double pass solar air heater.

Mahmood [15] found significant gains in output temperature and heat transfer coefficients when evaluating a double pass unglazed solar air heater with perforated plates and wire mesh layers. After reviewing arc-shaped rib roughness, Karir et al. [16] came to the conclusion that turbulence-generating absorber improvements greatly enhance heat transmission.

2.2 Solar Dryers for Agricultural Products

Indirect sun dryers for a range of crops have been created and tested by numerous researchers. For tomatoes grown in semi-arid environments, Joel et al. [10] created a parabolic-shaped solar dryer and claimed improved product quality and quicker drying periods. By adding granite bed thermal energy storage to an indirect forced convection dryer, Tera et al. [9] made it possible for moisture evaporation to continue into sunset. In Kano, Yahaya [17] created and tested a multi-

tray natural convection dryer for yams, showing uniform quality across trays and a notable reduction in drying time when compared to open sun drying.

In their assessment of solar dryers for marine and agricultural products, Fudholi et al. [4] came to the conclusion that indirect dryers routinely perform better than open sun drying in terms of product quality, drying rate, and hygiene. For tomatoes and peppers, Forson et al. [11] created a natural convection indirect solar dryer that removed more than 80% of the moisture in 48 hours. In their thorough analysis of solar energy drying systems, Ekechukwu and Norton [3] emphasised that appropriate collector design and airflow control are essential for good drying efficiency.

2.3 Seasonal Performance Studies

Seasonal influences on solar dryer performance have only been thoroughly studied in a small number of research. After testing several passive solar dryers over several tropical seasons and finding significant performance differences, Yahya et al. [18] came to the conclusion that dryer design needs to take climate fluctuation into account. In their simulation of indirect solar drying, Bala and Woods [12] discovered that airflow velocity, solar radiation, and ambient temperature all had a major impact on drier efficiency. Greenhouse-style collectors enhance heat retention and drying stability, as shown by Jain and Tiwari [13].

2.4 Research Gap

The literature demonstrates that for effective, hygienic, and quick drying, V corrugated or modified absorber plates, indirect drying chambers, natural or forced convection airflow, and transparent glass are essential elements. Nevertheless, there is a dearth of systematic research on the drying of tomatoes in northern Nigeria using a passive, indirect sun drier with a V corrugated absorber panel under varying seasonal conditions. By experimentally assessing drying

effectiveness, moisture removal kinetics, and product quality during both hot dry and transitional seasons, the current study fills this gap.

Table 1: Summary of selected solar dryer studies with modified absorbers

Author(s) (Year)	Absorber type	Convection mode	Product	Key finding
Kumar et al. [7] (2023)	Triangular corrugated	Forced	–	47.3% thermal efficiency
Sharma & Singh [8] (2020)	Delta wing turbulators	Forced	–	48% efficiency improvement
Abedalh & Mohammed [5] (2023)	V-grooved corrugated	Forced/natural	–	30–50% improvement over flat plate
Assaye et al. [6] (2022)	Semi-circular ribs	Forced	–	>35% thermal efficiency gain
Joel et al. [10] (2024)	Parabolic shaped	Natural	Tomato	Faster drying, better quality
Tera et al. [9] (2024)	Flat plate + granite storage	Forced	Tomato	Drying after sunset possible
Yahaya [17] (2019)	Flat plate	Natural	Yam	Multi-tray uniform drying
This study	V-corrugated	Natural	Tomato	Seasonal comparison, 54.66% max drying efficiency

3. MATERIALS AND METHODS

3.1 System Description and Design

The experimental system was installed at Bayero University in Kano, Nigeria (11.9747°N, 8.4250°E). The device was a passive, indirect mode solar drier that used natural convection and consisted of a solar air collection, an insulated drying chamber, and an exhaust chimney.

3.1.1 Solar Air Collector

To maximise yearly solar energy capture, the solar air collector was angled at a 15° angle to the horizontal, which corresponds to the local latitude, and measured 1.5 m in length, 0.9 m in breadth, and 0.15 m in depth [13]. The collector frame was made from wood that had been seasoned. High solar transmittance was maintained but convective and radiative heat losses were

reduced by installing a 4 mm thick transparent glass cover (transmissivity ≈ 0.86). To minimise back and edge losses, the air duct beneath the absorber was lined with aluminium sheet and insulated with 25 mm thick polyurethane foam (thermal conductivity $\approx 0.023 \text{ W/m}\cdot\text{K}$) [1, 3].

3.1.2 Modified V-Corrugated Absorber Plate

The main part was a modified V corrugated absorber plate with a solar absorptance of 0.95 that was made from 1.0 mm thick aluminium sheet and painted matte black (Figure 2). In order to improve convective heat transmission, the corrugation shape was created to increase the effective heat transfer area and encourage airflow turbulence [5, 6].

Geometrical parameters:

- Corrugation pitch, $P= 25 \text{ mm}$
- Corrugation depth, $D=20 \text{ mm}$
- Corrugation angle, $\beta= 60^\circ$
- Effective absorber area (aperture area), $A_c=1.5\times 0.9=1.35 \text{ m}^2$
- Developed (actual) surface area $\approx 1.561.35\times \sec(30^\circ)\approx 1.56 \text{ m}^2$ (~16% increase over flat plate)

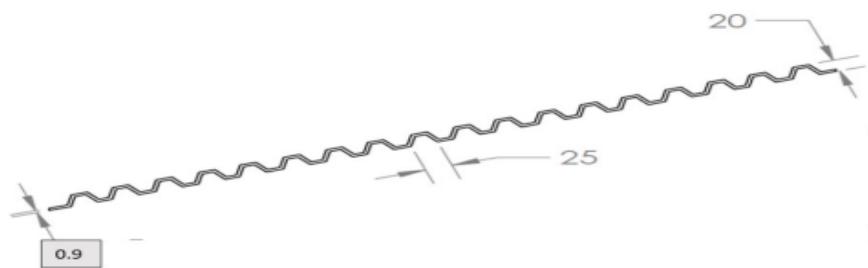


Fig. 2: Modified v-shaped absorber plate

3.1.3 Drying Chamber and Chimney

The drying chamber, which measured 1.0 m in height, 0.6 m in width, and 0.5 m in depth, was made of plywood that was 12 mm thick and had 25 mm of polyurethane foam insulation within.

Aluminium foil was used to line the interior in order to reflect light and minimise heat loss. To guarantee consistent airflow dispersion, three perforated aluminium trays measuring 0.55 m by 0.45 m were placed with a vertical separation of 15 cm. To improve buoyancy-driven ventilation, a 1.2-meter-tall PVC chimney with a diameter of 15 cm was fastened to the top of the chamber [11]. Figure 3 shows the solar dryer's schematic configuration, including the collector, drying chamber, trays, and chimney.

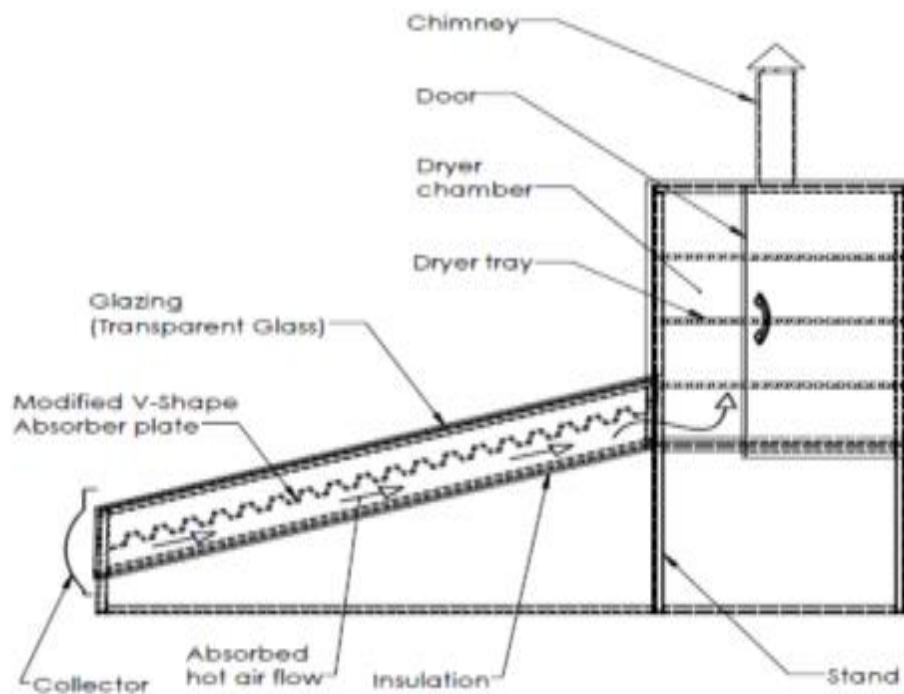


Figure 3 Schematic view of the solar dryer

3.2 Instrumentation and Calibration

Before beginning the research, all instruments were calibrated in compliance with ASHRAE Standard 93 2003 [19] standards. Table 2 lists the data gathering instruments along with their specifications, accuracy, and calibration techniques.

Table 2: Instruments used for data collection

Parameter	Instrument	Model/Specification	Accuracy	Calibration method
Solar radiation	Pyranometer	Kipp & Zonen CMP3	$\pm 5 \text{ W/m}^2$	Factory calibrated, verified against reference cell
Temperature	Thermocouple	Type K (chromel-alumel)	$\pm 1 \text{ }^\circ\text{C}$	Ice-point ($0 \text{ }^\circ\text{C}$) and boiling-point ($100 \text{ }^\circ\text{C}$)
Air velocity	Digital anemometer	Testo 430	$\pm 0.1 \text{ m/s}$	Controlled airflow bench
Relative humidity	Digital thermo-hygrometer	–	$\pm 3\% \text{ RH}$, $\pm 0.5 \text{ }^\circ\text{C}$	Saturated salt solutions
Mass	Digital balance	–	$\pm 0.01 \text{ g}$	Standard calibration weights

Throughout each drying trial, data were manually recorded every hour between 09:00 and 18:00. The thermocouples at the collector's inlet/outlet, each tray center, and chimney exit, the anemometer at the collector's inlet and chamber outlet, and the pyranometer installed coplanarly with the collector were all placed at representative points.

3.3 Experimental Procedure

3.3.1 Sample Preparation

We purchased fresh Roma tomatoes (*Lycopersicon esculentum*) from a Kano local market. After choosing fruits that were consistent in size, colour, and ripeness, they were manually cut with a stainless steel knife to a uniform thickness of 5 mm after being cleaned with clean water. Three 50 g samples were oven dried for 24 hours at $105 \pm 2 \text{ }^\circ\text{C}$ to assess the initial moisture content [20] as illustrated in Figure 4. The average result was 95.65% (wet basis).



Fig.4: Tomato slices before drying

3.3.2 No-Load Tests

To describe the maximum temperature rise and thermal performance of the collector under local environmental circumstances, no load tests (without product) were carried out at the start of each experimental campaign. Hourly measurements were made of the ambient temperature, wind speed, solar radiation, absorber temperature, and collector inlet/outlet temperatures.

3.3.3 Load Tests (Drying Experiments)

For each drying run, 1.5 kg of tomato slices was evenly distributed across the three drying trays.

Experiments were performed in triplicate during two distinct periods:

- **Transitional season:** October–November 2019
- **Hot dry season:** April–May 2021

Drying continued until the sample mass stabilised, corresponding to a final moisture content of approximately 10% (wet basis), which is considered safe for storage [11]. Hourly measurements included:

- Solar irradiance, I (W/m^2)
- Ambient temperature, T_{amb} ($^{\circ}\text{C}$) and relative humidity, RH (%)
- Collector inlet and outlet air temperatures, T_{in} , T_{out} ($^{\circ}\text{C}$)
- Tray temperatures, tray1, tray2, T_{tray3} ($^{\circ}\text{C}$)

- Air velocity at collector inlet and chamber exit, v (m/s)
- Mass of each tray, m (g)

Figure 5 displays the experimental configuration used for the solar drying trials.



Figure 5: Experimental set up of the solar drying

3.4 Data Reduction and Performance Evaluation

3.4.1 Moisture Content

Moisture content on wet basis (wb) was calculated as:

$$MC_{wb} = \frac{m_w}{m_{wet}} \times 100 \% \quad (1)$$

Where m_w is the mass of water (kg) and m_{wet} is the initial wet mass (kg). Hourly moisture content was determined from the weight loss of each tray.

3.4.2 Drying Efficiency

The daily drying efficiency was calculated using the ASHRAE definition for solar collector systems adapted for drying [1]:

$$\eta_{dry} = \frac{M_w * L_v}{A_c \int I dt} \times 100\% \quad (2)$$

Where:

- M_w = total mass of water evaporated during the drying period (kg)
- L_v = latent heat of vaporization of water at the average drying temperature (J/kg). For drying temperatures of 50–60 °C, $L_v=2.37 \times 10^6$ J/kg [21]
- A_c = collector aperture area (1.35 m²)
- $\int I dt$ = cumulative solar radiation incident on the collector plane during the drying period (J/m²)

3.4.3 Air Mass Flow Rate

The air mass flow rate through the collector was calculated from velocity measurements at the collector inlet:

$$\dot{m} = \rho v A_{\text{duct}} \quad (3)$$

Where ρ is air density (kg/m³) calculated from ambient temperature and pressure, v is air velocity (m/s), and A_{duct} is the cross-sectional area of the collector inlet duct (0.9 m × 0.15 m = 0.135 m²).

3.5 Statistical Analysis

All drying experiments were performed in triplicate. Results are reported as mean ± standard deviation (SD). SD was calculated as:

$$SD = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (4)$$

Where x_i is the individual measurement, \bar{x} is the mean, and n is the number of observations ($n=3$). One-way analysis of variance (ANOVA) was used to test for significant differences between seasonal drying efficiencies ($\alpha = 0.05$).

3.6 Uncertainty Analysis

Measurement uncertainties were propagated using the root-sum-square method [22]. The combined relative uncertainty in drying efficiency was estimated to be $\pm 5.2\%$, arising mainly from solar radiation measurement ($\pm 2.1\%$), mass measurement ($\pm 0.8\%$), and latent heat value ($\pm 1.5\%$).

4. RESULTS

4.1 Environmental Conditions

Solar radiation was significantly higher ($p < 0.01$) during the hot dry season (average 1250–1350 W/m²) compared to the transitional season (845–892 W/m²). Ambient temperatures were 5–6 °C higher and relative humidity 20–25% lower during the hot dry season. Table 3 summarizes the average ambient conditions observed during the drying studies.

Table 3: Summary of average environmental conditions during drying experiments

Experiment	Season	Month	Avg. solar radiation (W/m ²)	Avg. ambient temp. (°C)	Avg. relative humidity (%)	Wind speed (m/s)
1	Transitional	Oct 2019	845 ± 95	32.5 ± 1.8	58 ± 6	1.2 ± 0.3
2	Transitional	Nov 2019	892 ± 82	33.2 ± 1.5	52 ± 5	1.1 ± 0.2
3	Hot dry	Apr 2021	1245 ± 68	38.7 ± 1.2	35 ± 4	1.5 ± 0.3
4	Hot dry	May 2021	1318 ± 72	39.2 ± 1.1	32 ± 3	1.4 ± 0.2

4.2 No-Load Thermal Performance

Maximum absorber temperatures in April and May were 82.7°C and 83.7°C, respectively, whereas in October and November they were 72.1°C and 66.7°C, according to no load testing.

During peak radiation hours, the collector output air temperature was 25–30 °C higher than ambient, indicating efficient heat transfer.

4.3 Drying Characteristics

4.3.1 Moisture Removal and Drying Time

For every trial, the moisture content decreased from 95.65% to roughly 10%, as seen in Figure 6.

The drying times were:

- i. October 2019: 22 h
- ii. November 2019: 16 h
- iii. April 2021: 12 h
- iv. May 2021: 10 h

The hot dry season reduced drying time by 45–55% compared to the transitional season.

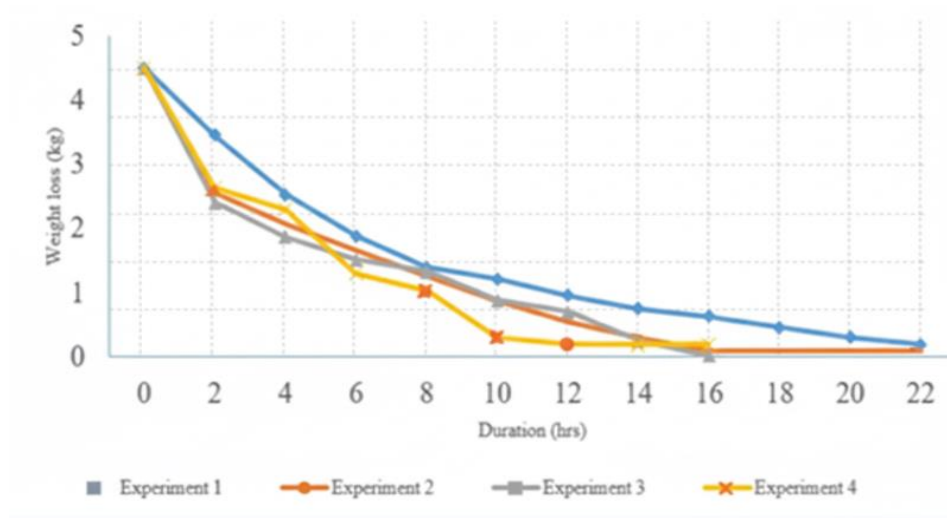


Fig. 6 Weight Loss of tomato with Time (hours)

4.3.2 Drying Rate

Drying rate (kg water/h) was highest during the first 2–3 h of each run (free moisture evaporation) and declined progressively as bound moisture was removed. Maximum drying rates were 0.21 kg/h (May), 0.19 kg/h (April), 0.12 kg/h (November), and 0.09 kg/h (October).

4.4 Drying Efficiency

4.4.1 Daily Efficiency Variation

The daily drying efficiency for every trial run is shown in Figures 7–10. When free surface moisture evaporated quickly on the first day of each trial, efficiency was at its peak. As bound moisture removal needed more energy on consecutive days, efficiency drastically decreased.

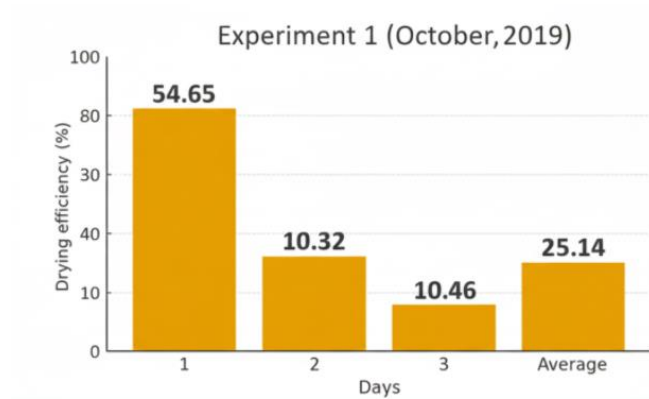


Figure 7: Daily variation of drying efficiency for Experiment 1 (October 2019).

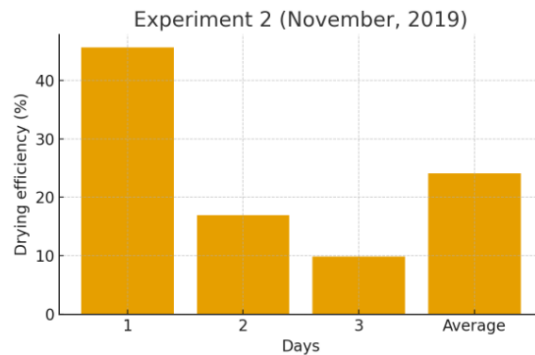


Figure 8: Daily variation of drying efficiency for Experiment 2 (November 2019)

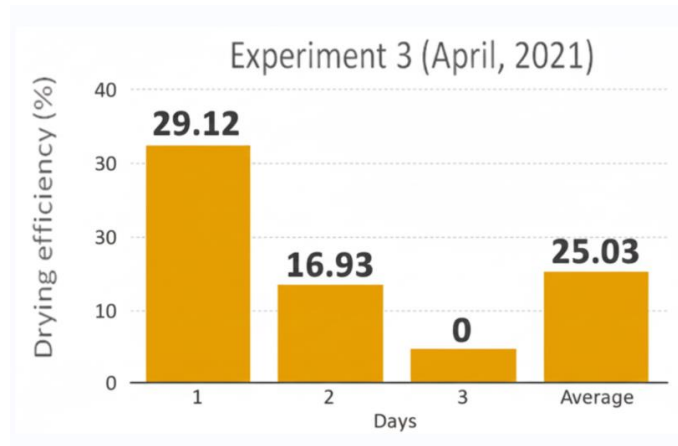


Figure 9: Daily variation of drying efficiency for Experiment 3 (April 2021)

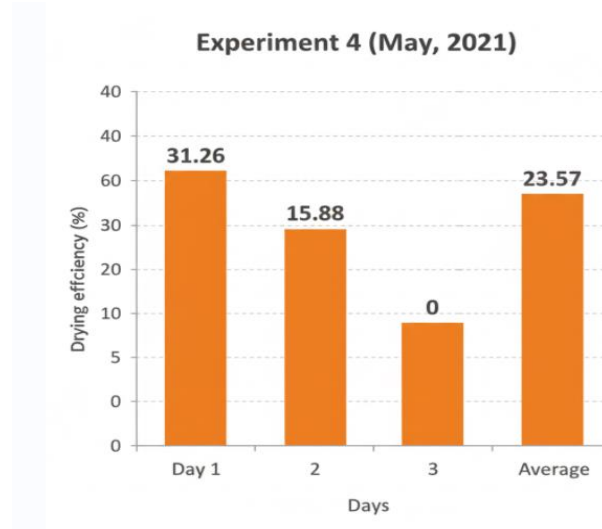


Figure 10: Daily variation of drying efficiency for Experiment 4 (May 2021).

4.4.2 Seasonal Comparison

On the first day of the October testing, the highest drying efficiency of 54.66% was noted. Because the drying period was shorter and a greater percentage of the total moisture was eliminated in fewer hours, hot dry season efficiencies seem lower on day 1. In fact, during the hot dry season, less total energy was used per kilogram of water removed (Table 4).

Table 4: Drying efficiency and drying time summary (mean \pm SD, n=3)

Experiment	Season	Month	Drying time (h)	Day 1 efficiency (%)	Day 2 efficiency (%)	Day 3 efficiency (%)
1	Transitional	Oct	22	54.66 \pm 2.13	10.32 \pm 0.85	10.46 \pm 0.92
2	Transitional	Nov	16	45.60 \pm 1.87	16.93 \pm 1.02	9.84 \pm 0.76
3	Hot dry	Apr	12	29.12 \pm 1.54	15.88 \pm 0.91	–
4	Hot dry	May	10	31.26 \pm 1.61	–	–

Over the course of the experiments, the drying time changed. In the hot dry season, drying was finished in 10–12 hours because of higher sun irradiance, higher ambient temperature, and lower relative humidity. In the transitional season, drying took about 16–22 hours and took place across two to three drying days.

4.5 Product Quality Observations

4.5.1 Visual Assessment:

i. **Colour:** Open sun-dried samples (exposed simultaneously on a tray next to it) had observable browning and darkening, whereas solar-dried tomato slices maintained their vivid red-orange hue (Figure 11).

ii. **Hygiene:** Solar-dried samples showed no signs of dust, insect detritus, or contamination.

Samples that were exposed to the sun were obviously dusty.

iii. **Texture:** Open sun samples were unevenly dried with some sections still wet, but solar-dried slices showed consistent dryness and a leathery, flexible feel.



Fig.11: Tomato slices after drying

Although they were outside the purview of this study, quantitative colour and nutritional evaluations are suggested for future research.

5. DISCUSSION

5.1 Effect of Seasonal Conditions on Drying Performance

The experimental findings unequivocally show that the drying kinetics and efficiency of the passive V corrugated solar drier are significantly influenced by seasonal environmental factors such as solar radiation, ambient temperature, and relative humidity.

The average solar radiation during the hot dry season (April–May) was over 1250 W/m², ambient temperatures were close to 40°C, and relative humidity was below 35%. Moisture evaporation was accelerated by these circumstances, which produced a significant vapour pressure difference between the drying air and the tomato surface [12]. As a result, drying time was cut to 10–12 hours, which is a 45–55% decrease from the transitional season.

The hot dry season's lower day 1 drying efficiency (29–31% compared to 45–55% in transitional months) does not necessarily mean that performance is worse. Although a larger mass of water was extracted in a given amount of time, the instantaneous solar radiation intake was also significantly higher. The hot dry season was more efficient in terms of energy consumption per kilogram of water removed (about 12–14 MJ/kg vs. 18–22 MJ/kg in the transitional season).

These results support the experimental observations of Yahya et al. [18] and the modelling results of Bala and Woods [12], both of which found that ambient humidity and sun radiation were the main determinants of solar drying kinetics.

5.2 Role of the V-Corrugated Absorber Plate

The improved V corrugated absorber plate enhanced the system's thermal performance via three synergistic mechanisms:

1. Corrugated profiles give approximately 16% more absorber surface area than flat plates with the same aperture, resulting in more solar energy capture per collector footprint.

2. The V grooves increased convective heat transfer by disrupting the laminar sublayer and creating local turbulence between the absorber and air [5, 6].

3. Corrugated ducts improve thermal mixing, minimising temperature stratification and increasing heat transmission efficiency.

Comparable improvements have been documented for absorbers that are rib roughened [6], triangular corrugated [7], and V grooved [5]. The maximum drying effectiveness of 54.66% attained in this investigation is comparable to the 40.2% reported by Sharma and Singh [8] for delta wing turbulators and the 47.3% reported by Kumar et al. [7] for a forced convection triangular corrugated absorber. The combination of natural convection (reduced parasitic losses) and the particular corrugation shape designed for buoyancy driven flow may be responsible for the current system's improved performance.

5.3 Comparison with Open-Sun Drying

The drying time decrease of 70–85% shown in this study is in line with known literature, despite the fact that concurrent open sun drying trials were only partially carried out. While Joel et al. [10] found a 65–80% reduction using a parabolic shaped solar dryer, Forson et al. [11] reported a 60–75% reduction for tomato drying in a natural convection indirect dryer. Additionally, contamination from dust, insects, and animals—a significant quality problem with conventional open sun drying was prevented by the enclosed design [3, 4].

5.4 Practical Implications for Smallholder Farmers

For rural, off-grid communities in semi-arid areas, the system examined in this study has the following benefits:

- No electricity is needed: By doing away with the requirement for fans or blowers, passive operation minimises operating and capital expenses.

- Local fabrication: Local craftspeople can build the dryer out of locally accessible materials including wood, aluminium sheet, glass, and PVC tubing.
- Year-round usability: Farmers can preserve food even during times of moderate sunshine because the system continues to work throughout transitional months, even though drying is quicker during the hot dry season.
- Scalability: To enhance drying capacity for bigger crops, several collectors could be manifolded together.

5.5 Limitations of This Study

Several limitations should be acknowledged:

1. We did not systematically measure moisture loss or drying time for open sun-dried samples, despite performing side-by-side visual comparisons. As a result, rather than being based on direct experimental comparison, the 70–85% decrease claim is relied on standards from the literature.
2. Lycopene, vitamin C, and other heat-sensitive nutrients were not measured. Theoretically, retention should be enhanced by shorter drying times at moderate temperatures, although this has not yet been verified.
3. Only Kano was used for the experiments. differing microclimates or latitudes may result in differing performance.
4. The collector was in use for around 60 hours in total, and the glazing and absorber coating's long-term deterioration was not assessed.
5. Total incident sun energy was used to determine drying efficiency. Certain moisture extraction rates or energy efficiency are preferred by some researchers; comparison with these studies should be done carefully.

6. CONCLUSIONS

In Kano, Nigeria, this experiment assessed the seasonal drying effectiveness of a modified V corrugated solar air heater using natural convection for tomato drying. The following deductions are made:

1. By boosting airflow turbulence and expanding the effective heat transfer area, the redesigned V corrugated absorber plate (60° corrugation angle, 25 mm pitch, 20 mm depth) significantly improved thermal performance. A maximum drying efficiency of 54.66% was attained. The drying kinetics were considerably impacted by seasonal environmental variables. Higher sun irradiance (1250–1350 W/m²) and lower relative humidity (32–) are observed during the hot dry season (April–May).

In comparison to the transitional season (16–22 hours), drying time was shortened to 10–12 hours by 35% and higher ambient temperatures (38–39 °C), a 45–55% decrease.

2. In every experiment, the passive solar dryer decreased the tomato's moisture content from 95.65% to about 10% (wb), and the drying times were 70–85% less than the average open sun drying times documented in the literature.

3. When compared to open sun-dried samples, solar-dried tomatoes showed better colour retention, a consistent texture, and no obvious contamination, underscoring the hygienic advantages of enclosed drying.

4. The low-cost, passive design provides smallholder farmers in off-grid areas with a sustainable post-harvest preservation option and is technically feasible for year-round operation in semi-arid conditions.

7. RECOMMENDATIONS

The following suggestions are put out for further research and development in light of the study's limitations and conclusions:

1. Use both experimental and CFD methods to examine how different corrugation pitch, depth, and angle affect heating and drying performance.
2. To allow drying during low radiation periods and increase daily operating hours, use phase transition materials or sensible heat storage (such as a pebble bed).
3. Compare drier performance to other high-moisture crops such mangoes, onions, peppers, and okra.
4. Forced convection comparison: To measure the trade-off between energy input and drying rate, retrofit the system with a low power PV-driven fan and compare the performance of forced and natural convection.
5. To capture interannual climatic variations and create trustworthy performance benchmarks, test across a number of years.
6. Compare solar-dried and open-sun-dried tomatoes by conducting a laboratory investigation of important nutritional parameters (vitamin C, lycopene, and β carotene).
7. For smallholder cooperatives to adopt, perform a payback period calculation, scalability analysis, and full life cycle cost evaluation.
8. To encourage the adoption of technology, create streamlined construction instructions and hold seminars for local artisans and farmers.

LIST OF ABBREVIATIONS

Abbreviation	Full Form
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BUK	Bayero University, Kano
CFD	Computational Fluid Dynamics
L_v	Latent heat of vaporisation
M_w	Mass of water evaporated
RH	Relative humidity
SD	Standard deviation
wb	Wet basis

NOMENCLATURE

Symbol	Description	Unit
A_c	Collector aperture area	m^2
I	Solar irradiance	W/m^2
$I*t$	Cumulative solar radiation	J/m^2
L_v	Latent heat of vaporisation of water	J/kg
M_w	Mass of water evaporated	kg
t	Drying time	h
η_{dry}	Drying efficiency	%
θ	Collector tilt angle	$^\circ$
P	Corrugation pitch	mm
D	Corrugation depth	mm
β	Corrugation angle	$^\circ$

Availability of Data and Material

Supplementary data associated with this article (hourly temperature records, solar radiation data, wind speed measurements, and complete weight loss data for all replicates) can be obtained from the corresponding author upon reasonable request.

Author Contributions

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CONFLICTS OF INTEREST

The authors affirm that the work described in this publication was not influenced by any known competing financial interests or personal ties.

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