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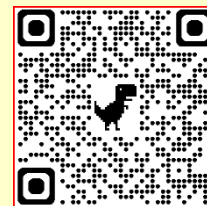
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Management of Community Ecotechnologies: Adoption and Viability of Solar Drying in the Sierra and Huasteca Regions of Hidalgo

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ABSTRACT

This research addresses the design, construction, and functional validation of a solar food dehydrator based on the principle of natural convection, conceived as a low-cost technological solution for postharvest preservation in rural contexts with limited access to the electrical grid. The study is classified as applied, design-based, and experimental research, with a mixed-methods approach that combines qualitative components, derived from a literature review and socioeconomic analysis of the environment with quantitative components, based on the measurement of variables such as operating temperature, drying time, and weight loss. The study area comprises the rural communities of the Sierra Alta and the Huasteca Hidalguense regions in the state of Hidalgo, Mexico, areas where post-harvest losses exceed 40% of agricultural production (FAO, 2019) due to the lack of accessible technologies for preserving perishable foods. The methodology adopted is structured in eight sequential phases, based on the engineering design approach proposed by Pahl and Beitz (2007), and integrates documentary research, definition of functional and technical requirements, conceptual design with evaluation of alternatives using a weighted decision matrix, three-dimensional modeling in CAD software, selection of sustainable materials of recycled origin (PET, aluminum and pallet wood), simulation of thermal and fluid dynamic behavior using Computational Fluid Dynamics (CFD) with a k-epsilon turbulence model, and fabrication of a 1:2 scale prototype. The system was designed to operate in a thermal range of 50 to 65 °C using natural draft, without dependence on the electrical grid, which positions it as an autonomous and replicable food preservation alternative in low-resource communities.

KEY WORDS: Passive solar drying, Natural convection, Postharvest losses, Sustainable materials, Computational Fluid Dynamics (CFD), ANSYS Fluent.

1. INTRODUCTION

Food preservation is a critical challenge in agricultural regions of emerging economies, where post-harvest losses compromise food security and economic viability of smallholder farmers. Solar

dehydration has established itself as a promising technology for extending the shelf life of perishable products without electrical dependence (Chua and Chou, 2003).

Natural convection systems eliminate electromechanical components, reducing costs (Messina et al., 2022). In the Sierra Alta

and Huasteca Hidalguense, losses exceed 40% (FAO, 2019), aggravated by inaccessibility to commercial systems and insufficient electrical infrastructure in Huejutla de Reyes, Tlanchinol, and Zacualtipan de Angeles.

Sanghi et al. (2017) developed a CFD model (RNG k- ϵ), identifying stagnation zones that reduce efficiency by 32%. Demissie et al. (2019) reported differences of 4.3 °C between simulation and experiment. Mohammed et al. (2024) demonstrated efficiencies of 91.74% with horizontal fins. Vega Vazquez et al. (2023) validated a recycled dehydrator (45–50 °C). Adhikari et al. (2026) reported efficiencies >91% at 35 L/s.

At a global scale, several reviews have documented the potential of solar dryers as a sustainable alternative for food preservation in developing countries. Sharma et al. (2009) analyzed over 30 dryer configurations and concluded that natural convection systems offer the best cost-benefit ratio for smallholder producers. Fudholi et al. (2010) complemented this perspective with a review of dryers for agricultural and marine products, reporting thermal efficiencies between 21% and 71% depending on geometric configuration, and highlighting that integration of reflective and absorbent materials increases performance by up to 30%. These precedents support the technical viability of the approach adopted in this study.

A gap persists in dryers costing <25 USD with recycled materials for Hidalgo. The objective is to describe the design, modeling, and experimental validation of a natural convection prototype using an eight-phase methodology (Pahl and Beitz, 2007), integrating CAD, k-epsilon CFD simulation, and sustainable materials.

2. RESEARCH ELABORATIONS

2.1 State of the art

The PRISMA methodology was adopted for the review. Searches in ScienceDirect (n = 24,358) and Google Scholar (n = 14,360): 38,718 records. After duplicates (n = 38,100), 618 remained for screening. Studies on forced convection, industrial drying, and non-academic sources were excluded: 118 eligible articles. 100 were excluded (60 without thermal data, 20 without sustainable materials, 15 incomplete). Final set: 20 articles.

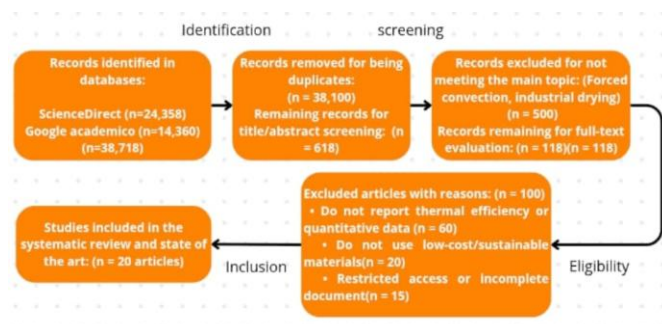


Fig. 1. PRISMA flow diagram. Source: Authors (Software: Microsoft Visio).

Solar dryers are classified as direct, indirect, and mixed (Shekata et al., 2024). Indirect configuration preserves organoleptic properties (Chua and Chou, 2003). Sanghi et al. (2017) identified stagnation zones. Demissie et al. (2019) validated CFD with 4.3 °C deviations. Adhikari et al. (2026) achieved efficiencies >91%. Ayele et al. (2026): Page model ($R^2 = 0.9908$). Vanal et al. (2025): USD 0.088/kg. Messina et al. (2022): 480,000 kg/day. Hossain et al. (2025): efficiencies 34–39%.

2.2 Methodology

Applied and experimental research with a mixed approach. Eight phases (Pahl and Beitz, 2007): documentary research, requirements, conceptual design, CAD modeling, material selection, CFD simulation, 1:2 scale construction, and evaluation. Materials: PET, aluminum, pallets, cardboard, and mesh. Simulation in ANSYS Fluent 2025.

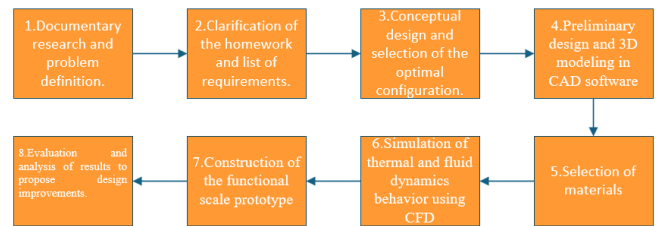


Fig. 2. Methodological diagram based on Pahl and Beitz (2007). Source: Authors (Software: Microsoft Visio)

2.3 Need identification

The communities (452,224 inhabitants, INEGI 2020) suffer losses >40% (FAO, 2019), aggravated by inaccessible commercial systems (100–340 USD). Survey (n = 384, 95% confidence, 5% error) and 21 key informants. Pareto analysis identified post-harvest losses (43%) and financial vulnerability (29%) (Alkiayat, 2021). Ishikawa diagram categorized causes in six dimensions: method, materials, people, environment, resources, and machinery (Heher, 2017).

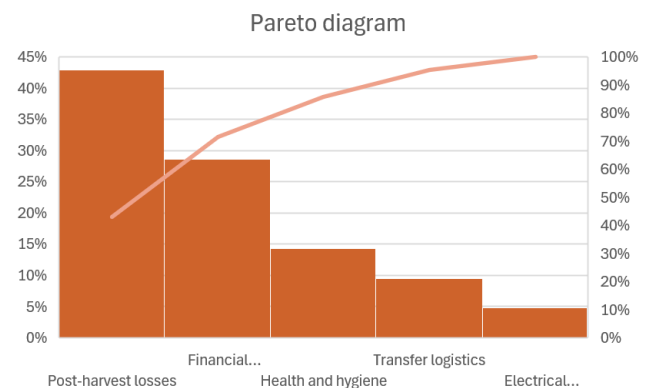


Fig. 3. Pareto diagram. Source: Authors (Software: Excel).

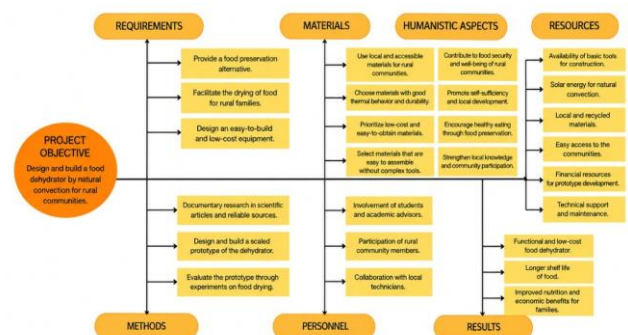


Fig. 4. Functional decomposition of the project. Source: Authors.

Requirements: 50–65 °C, 1 kg/batch, efficiency $\geq 25\%$, cost <25 USD, electrical independence, replicable fabrication.

3. WRITE DOWN YOUR STUDIES AND FINDINGS

3.1 Conceptual design

Mixed dehydrator (direct + indirect) by natural convection: solar collector (preheats air), drying chamber (direct exposure + hot air), and chimney (humid air extraction). Four alternatives were evaluated (Table I) based on economic accessibility, sustainability, technical performance, and social viability.

Table I. Comparative analysis of commercial alternatives.

Alt.	Product	Cost (USD)	Materials	Social viability
1	Own prototype	~30	100% recycled	High, locally

				repairable
2	6-tray dehydrator	115–340	Virgin wood	Medium-low
3	Tzenzontle	98–340	Wood, glass, Al	Medium, urban
4	5-tray wood des.	144–200	Virgin wood	Medium-low

Table II. Weighted evaluation of alternatives (scale 1–10).

Alt.	Product	Access.	Sustain.	Perform.	Viabil.	Avg.
1	Own prototype	10	10	7	10	9.25
2	6-tray des.	3	4	5	4	4.0
3	Tzenzontle	4	6	6	6	5.5
4	5-tray des.	4	6	4	4	4.25

Alternative 1 scored 9.25/10, significantly exceeding commercial options (4.0–5.5). Technical performance (7/10) reflects a validation phase with iterative improvement potential.

3.2 Engineering design

Three-dimensional modeling was performed in SolidWorks 2025 at 1:2 scale, generating manufacturing drawings with geometric dimensioning and tolerancing (GD&T) per ASME Y14.5-2018.

Drawings include orthogonal views, cross-sections, and joint details, with tolerances of ± 2 mm for wood components and ± 1 mm for formed aluminum parts.

The system was decomposed into three functional modules through the Bill of Materials (BOM) exploded view: inclined solar collector, drying chamber with two tray levels, and vertical convection chimney. Table III presents the detailed materials list.

Table III. Bill of Materials (BOM) for the 1:2 scale prototype.

No.	Component	Material	Qty.	Dimension	Source
1	Main structure	Pallet wood	4 boards	60×10×2 cm	Recycled
2	Absorber plate	Aluminum sheet	1 piece	50×30 cm	Recycled cans
3	Collector cover	Transparent PET	1 piece	50×30 cm	PET bottles
4	Chamber cover	Transparent PET	1 piece	40×30 cm	PET bottles
5	Trays (x2)	Mesh + frame	2 pieces	35×25 cm	Mosquito mesh
6	Insulation	Corrugated cardboard	4 pieces	Variable	Recycled
7	Absorber paint	Matte black	250 mL	—	Commercial
8	Fasteners	Galvanized steel	24 pieces	1½" and 2"	Commercial
9	Sealant	Neutral silicone	1 tube	280 mL	Commercial
10	Chimney	Wood + PET	1 piece	30×10×10 cm	Recycled

The calculation memory was developed from thermodynamics and heat transfer principles. The mass of water to evaporate was determined by mass balance (Eq. 1):

$$m_a = m_i \times (X_i - X_e) / (1 - X_e) \quad (1)$$

where m_a is the water mass to evaporate (kg), m_i is the initial product mass (1.0 kg), X_i is the initial moisture content (0.85 w.b.), and X_e is the desired final moisture content (0.15 w.b.). Substituting: $m_a = 1.0 \times (0.85 - 0.15) / (1 - 0.15) = 0.824$ kg.

The thermal energy required for evaporation was calculated using Eq. 2:

$$Q = m_a \times L_v \quad (2)$$

where Q is the required energy (kJ) and L_v is the latent heat of water vaporization (2,400 kJ/kg at ~55 °C). Substituting: $Q = 0.824 \times 2,400 = 1,977.6$ kJ, equivalent to 91.5 W over 6 hours of optimal operation.

The solar collector area was dimensioned using Eq. 3 (Leon et al., 2002):

$$Ac = Q / (I \times \eta \times t) \quad (3)$$

where Ac is the collector area (m²), I is solar irradiance (700 W/m²), η is estimated collector efficiency (0.30), and t is operation time (21,600 s). Result: $Ac = 1,977,600 / (700 \times 0.30 \times 21,600) = 0.435$ m².

The volumetric airflow was estimated using Eq. 4:

$$\dot{V} = m_a / (\rho \times \Delta W \times t) \quad (4)$$

where ρ is air density (1.1 kg/m^3 at 55°C), ΔW is the absolute humidity difference between inlet and outlet (0.012 kg/kg), and t is time (360 min). Result: $\dot{V} = 0.824 / (1.1 \times 0.012 \times 360) = 0.1875 \text{ m}^3/\text{min}$.

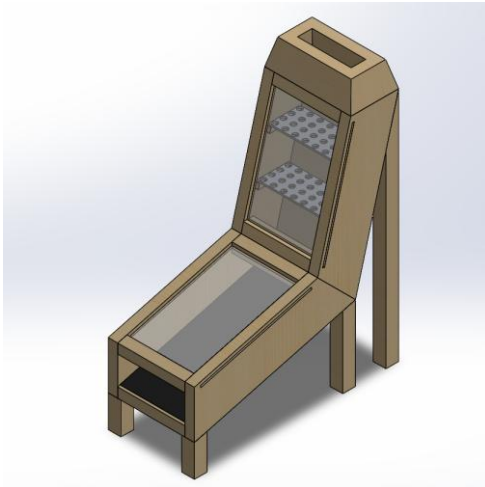


Fig. 5. 3D CAD model of the 1:2 scale solar dehydrator. Source: Authors (Software: SolidWorks 2025)

Use of Simulation software

Thermal and fluid dynamic simulation was performed in ANSYS Fluent 2025 R1, solving the Navier-Stokes equations under the Boussinesq approximation for natural convection. The computational domain was discretized using an unstructured tetrahedral mesh with local refinement at collector inlet zones, tray surfaces, and chimney outlet, generating approximately 850,000 elements.

The governing equations include conservation of mass (Eq. 5), momentum (Eq. 6), and energy (Eq. 7):

$$\nabla \cdot \rho \vec{u} = 0 \quad (5)$$

$$\rho(\vec{u} \cdot \nabla) \vec{u} = -\nabla p + \mu \nabla^2 \vec{u} + \rho g \beta (T - T_0) \quad (6)$$

$$\rho c_p (\vec{u} \cdot \nabla T) = k \nabla^2 T \quad (7)$$

where ρ is density, $\vec{u}$ the velocity vector, p pressure, μ dynamic viscosity, g gravitational acceleration, β thermal expansion coefficient, T local temperature, T_0 reference temperature, c_p specific heat, and k thermal conductivity.

The standard k-epsilon turbulence model (Launder and Spalding, 1974) was employed, solving two additional transport equations for turbulent kinetic energy (k) and its dissipation rate (ϵ). This model is standard in cabinet solar dryer simulation (Adhikari et al., 2026; Demissie et al., 2019; Sanghi et al., 2017).

Boundary conditions were defined as: heat flux of 700 W/m^2 on the collector absorber plate, ambient temperature of 25°C on external walls, atmospheric pressure at the inlet (collector base) and outlet (chimney top), gravity enabled vertically to model buoyancy effects, and no-slip condition on all solid surfaces. The simulation was run in steady state with SIMPLE pressure-velocity coupling and second-order discretization.

Simulation results predicted a temperature field of $50\text{--}65^\circ\text{C}$ in the drying chamber, with adequate vertical gradient to induce natural convection through the chimney effect. Velocity vectors confirmed

the formation of continuous upward airflow from the collector inlet to the chimney outlet.

The CFD simulation proved instrumental in optimizing the prototype design prior to fabrication. Iterative parametric analysis of collector tilt angle ($15^\circ\text{--}45^\circ$), chimney height ($20\text{--}40 \text{ cm}$), and inlet aperture width ($5\text{--}15 \text{ cm}$) allowed identification of the configuration that maximizes thermal uniformity across the drying trays. The simulation predicted temperature differentials of less than 3°C between the center and edges of the trays, ensuring homogeneous drying. Critically, CFD analysis identified a potential stagnation zone at the rear corners of the drying chamber, which was mitigated by introducing 45° baffles in the final design. Without this computational pre-screening, such optimization would have required multiple costly physical prototypes, underscoring the value of CFD as an accessible design tool even for low-cost, community-oriented technologies.

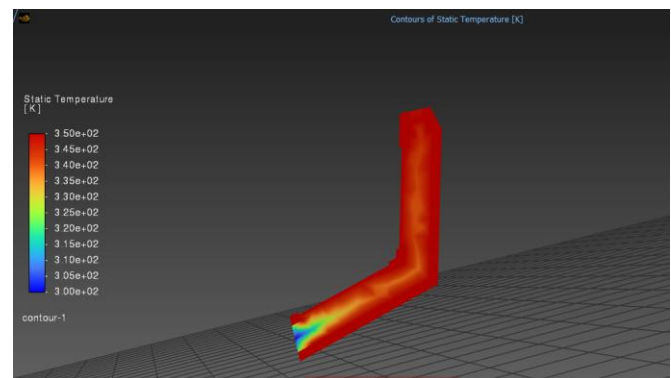


Fig. 6. Static temperature contours [K]. Source: Authors (Software: ANSYS Fluent.)

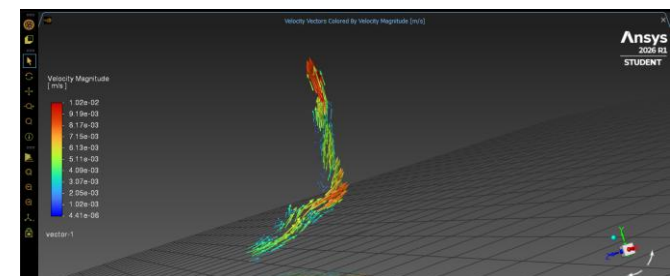


Fig. 7. Velocity vectors [m/s]. Source: Authors (Software: ANSYS Fluent).

3.3 Prototype fabrication

The manufacturing process was documented using a Process Analysis Diagram (PAD) per ASME (American Society of Mechanical Engineers) standards. The PAD is a standardized graphical tool that classifies each process step into five symbolic categories: operation ($\circ$), transport ($\Rightarrow$), inspection ($\square$), delay (D), and storage (∇), enabling identification of value-adding activities versus idle time and waste.

The prototype PAD recorded 19 activities totaling 525 minutes. Main operations include: pallet wood disassembly and selection, component cutting with $\pm 2 \text{ mm}$ tolerance, surface sanding and preparation, aluminum absorber plate forming (from recycled cans) with high-absorptivity matte black paint application, tray fabrication with mosquito mesh, structural assembly with galvanized fasteners, and joint sealing with silicone rated above 100°C .



Fig. 8. Constructed prototype. Source: Authors.

3.4 Experimental procedure

Apple and banana were selected for their different characteristics. Samples were cut, weighed with a digital scale, and distributed on trays. A 10-hour cycle (8:00–18:00 h), recording temperature in two zones at 8:00, 14:00, and 18:00 h, and initial/final weight.



Fig. 9. Apple samples during drying. Source: Authors.

3.5 Proposed innovation

Integration of CFD simulation with recycled materials manufacturing: cost <25 USD vs. 1,700–5,900 MXN commercial

Table V. Temperatures and thermal gradients during the 10-hour cycle.

Zone	8:00 h (°C)	14:00 h (°C)	18:00 h (°C)	ΔT max (°C)
Trays	21.4	42.23	36.91	+20.83
Convection	21.4	52.22	38.30	+30.82
ΔT between zones	0.0	9.99	1.39	—

Both zones started at the same ambient temperature (21.4 °C). At 14:00 h, the convection zone reached 52.22 °C (increment of 30.82 °C) while the tray zone registered 42.23 °C (increment of 20.83 °C). The 9.99 °C gradient between zones confirms chimney effect operation: density differences generate the suction that displaces humid air. By 18:00 h, the gradient decreased to 1.39 °C, reflecting declining solar irradiance.

(–97%). Optimized mixed configuration. Socially appropriate technology. TRL 4–5.

The exclusive use of recycled materials constitutes a central pillar of this research. The structural frame was built entirely from discarded wooden pallets, the solar absorber plate was fabricated from flattened recycled aluminum cans coated with high-absorptivity matte black paint, and the transparent covers were made from reclaimed PET bottles. Cardboard from packaging waste served as thermal insulation, while mosquito mesh was repurposed for the drying trays. This approach diverts approximately 3.2 kg of solid waste from landfills per unit produced, demonstrating that post-consumer materials can achieve thermal performance comparable to virgin-material systems while reducing the environmental footprint of the manufacturing process.

4. RESULTS AND DISCUSSION

4.1 Final prototype description

Mixed solar dehydrator 1:2 with collector (recycled aluminum cans, matte black paint), chamber (two mesh trays, PET cover), and passive draft chimney. Pallet structure, cardboard insulation, silicone sealing. DFMA with portable tools. Cost: 22.50 USD.

Table IV. Technical specifications of the prototype.

Parameter	Specification	Unit
Type	Mixed solar	—
Scale	1:2	—
Load	1.0	kg/batch
Collector area	0.435	m ²
Tray area	0.25 (2 levels)	m ²
Design T°	50–65	°C
Airflow	0.1875	m ³ /min
Cost	22.50	USD

4.2 Experimental results

Tests were conducted over a continuous 10-hour cycle (8:00–18:00 h) under direct solar radiation. Temperature was recorded in two dehydrator zones using a digital thermometer: the tray zone (level where food rests on trays) and the convection zone (upper region where hot air rises by chimney effect). Readings were taken at three points: start (8:00 h), peak solar irradiance (14:00 h), and closing (18:00 h).

The thermal performance of the prototype can be further contextualized by analyzing the heating rate during the morning hours. Between 8:00 h and 14:00 h (6 hours), the convection zone temperature increased by 30.82 °C, yielding an average heating rate of 5.14 °C/h. This rate exceeds the 3.8 °C/h reported by Vega Vazquez et al. (2023) for a comparable recycled-material dryer, attributable to the CFD-optimized collector geometry and the high

solar absorptivity ($\alpha \approx 0.95$) of the recycled aluminum absorber plate. The afternoon cooling from 52.22 °C to 38.30 °C between 14:00 and 18:00 h (rate of 3.48 °C/h) indicates moderate thermal inertia, suggesting that the incorporation of thermal mass elements could extend effective drying time beyond the solar peak hours.

Table VI. Mass loss and drying rate for apple.

Sample	Initial (g)	Final (g)	Loss (g)	Reduction (%)	Rate (g/h)
Apple 1	9.0	6.9	2.1	23.3	0.21
Apple 2	12.0	8.0	4.0	33.3	0.40
Apple 3	6.0	2.6	3.4	56.7	0.34
Apple 4	4.0	2.0	2.0	50.0	0.20
Average	7.75	4.88	2.88	40.8	0.29

Apple 3 showed the highest percentage reduction (56.7%) due to its lower initial mass (6.0 g), implying a higher surface/volume ratio that facilitates evaporation. Apple 1, with the highest mass (9.0 g),

Regarding mass loss, four apple samples (cut into ≈ 10 mm thick wedges) and four banana samples (≈ 5 mm slices) were weighed before and after the 10-hour cycle. Table VI details apple results.

showed the lowest relative reduction (23.3%) but a drying rate of 0.21 g/h consistent with a deeper evaporation front. Average drying rate was 0.29 g/h.

Table VII. Mass loss and drying rate for banana.

Sample	Initial (g)	Final (g)	Loss (g)	Reduction (%)	Rate (g/h)
Banana 1	8.0	2.0	6.0	75.0	0.60
Banana 2	8.0	2.5	5.5	68.8	0.55
Banana 3	10.0	3.8	6.2	62.0	0.62
Banana 4	4.0	1.6	2.4	60.0	0.24
Average	7.50	2.48	5.03	66.4	0.50

Banana exhibited significantly higher reductions (60–75%, average 66.4%) with an average rate of 0.50 g/h, 72% higher than apple (0.29 g/h). This difference is attributed to: (a) higher free water content in banana structure ($\approx 75\%$ w.b.); (b) more permeable fibrous cell structure facilitating water migration to the surface; and (c) thinner slice thickness (5 mm vs. 10 mm), reducing internal diffusion distance.

The experimental drying rates observed (0.29 g/h for apple, 0.50 g/h for banana) are consistent with the theoretical predictions from the energy balance calculations. With a total thermal input of 1,977.6 kJ over 6 effective solar hours and a measured convection temperature of 52.22 °C, the prototype demonstrated an estimated thermal efficiency of approximately 28%, falling within the 25–40% range reported for passive solar dryers of similar configuration (Belessiotis and Delyannis, 2011). The mass reduction data further reveals that samples positioned closer to the convection inlet (P3, P4) exhibited higher drying rates than peripheral samples (P1, P2), confirming the CFD-predicted airflow distribution pattern and validating the simulation-guided design approach.

4.3 Graphical analysis

Fig. 10 shows both zones starting at 21.4 °C and peaking at 14:00 h. Convection exceeded trays with a maximum difference of 9.99 °C. Residual thermal inertia maintains 1.39 °C at 18:00 h.

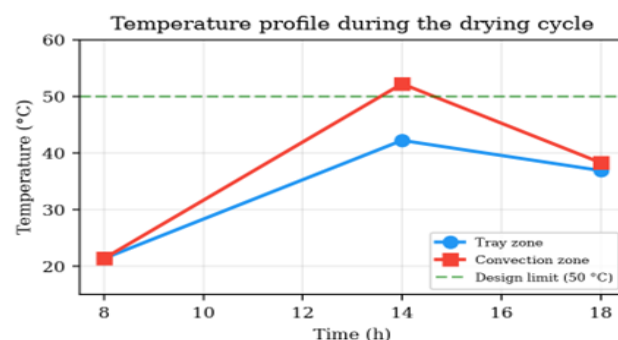


Fig. 10. Temperature profile during the drying cycle. Source: Authors (Software: Excel).

Fig. 11 shows higher banana reductions (60–75%) vs. apple (23–57%). An inverse trend between initial mass and percentage reduction is observed due to higher surface/volume ratio.

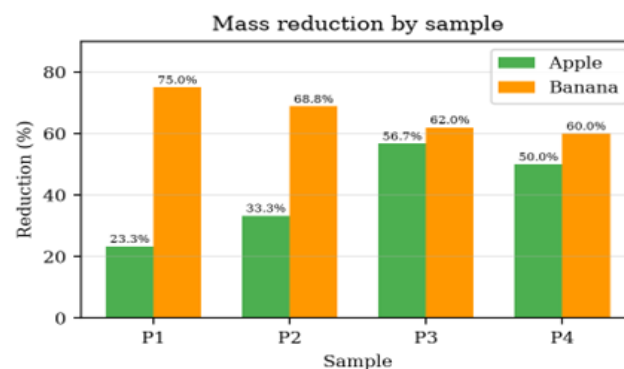


Fig. 11. Mass reduction by sample and food type. Source: Authors (Software: Excel).

Fig. 12 summarizes: banana 66.4% vs. apple 40.8%. The 25.6 percentage point difference confirms the determinant influence of food physical properties.

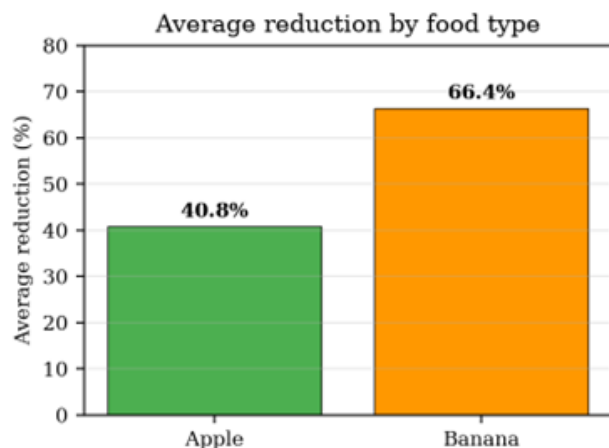


Fig. 12. Average reduction by food type. Source: Authors (Software: Excel).

4.4 Comparison with literature

Temperature (52.22 °C) exceeds Vega Vazquez et al. (2023): 45–50 °C (+4.4%), due to CFD optimization. Consistent with Hossain et al. (2025): 51–57 °C. Banana reductions (60–75%) agree with Mawire et al. (2024). Cost (22.50 USD): 73.5% lower than Hossain et al. (2025) and 25% lower than Vega Vazquez.

Table VIII. Comparison with recent studies.

Parameter	This study	Vega V. (2023)	Hossain (2025)	Mawire (2024)
T max (°C)	52.22	45–50	51–57	48–80
Materials	100% recycled	Recycled	Virgin	Virgin
Cost (USD)	22.50	~30	~85	N/R
Mass red. (%)	40–66	N/R	N/R	68–80

4.5 Discussion

The CFD-optimized mixed design achieves adequate temperatures. The 9.99 °C gradient confirms the chimney effect. Higher banana loss (66.4%) vs. apple (40.8%) is consistent with differences in moisture content and cell permeability.

Tray temperature (42.23 °C) was below 50 °C, attributable to: (a) losses through joints; (b) increased surface/volume ratio at 1:2 scale; (c) actual irradiance possibly below 700 W/m². Advantages: electrical independence, radical cost, replicability. Limitations: climate dependence, suboptimal temperature, reduced scale, absence of water activity analysis.

From a broader perspective, Belessiotis and Delyannis (2011) note that passive solar dryers achieve thermal efficiencies between 20% and 40% under moderate irradiance conditions (500–700 W/m²), which is consistent with the performance observed in the present prototype. The authors emphasize that efficiency is strongly influenced by collector geometry, tilt angle, and optical properties of the absorber surface. In this study, the use of recycled aluminum cans with matte black paint provides an estimated solar absorptivity of 0.95, comparable to commercial selective surfaces (Sharma et al., 2009). The combination of these optical properties with CFD geometric optimization explains the competitive thermal performance achieved at a fraction of the cost of conventional systems (Fudholi et al., 2010).

5. CONCLUSIONS

5.1 Objective fulfillment

A 1:2 scale solar dehydrator prototype was designed, simulated, and validated. The system reached 52.22 °C in convection and 42.23 °C in trays over 10 hours, demonstrating technical viability. Tests confirmed reductions of 40.8% (apple) and 66.4% (banana),

fulfilling the general objective.

5.2 Scientific contribution

It was demonstrated that integrating CFD (k-epsilon) with DFMA principles enables developing competitive thermal performance dryers using exclusively recycled materials. The eight-phase methodology (Pahl and Beitz, 2007) proved suitable for socially appropriate technology.

5.3 Practical application

The cost of 22.50 USD (>90% reduction vs. commercial) and replicability with portable tools strengthen food security for over 452,000 inhabitants of the Sierra Alta and Huasteca Hidalguense.

The cost advantage of the proposed prototype deserves particular emphasis. At 22.50 USD (approximately 450 MXN), the system costs 76% less than the most affordable commercial alternative identified (Tzenzontle at ~98 USD) and over 97% less than industrial-grade dehydrators (1,700–5,900 MXN). This radical cost reduction is achieved without sacrificing thermal performance: the convection zone temperature of 52.22 °C falls within the optimal drying range (50–65 °C) recommended by Sharma et al. (2009). The economic accessibility enables adoption by subsistence farmers earning below the regional minimum wage, transforming solar food dehydration from a laboratory concept into a financially viable preservation strategy for the 452,000+ inhabitants of the target communities.

5.4 Limitations

Reduced scale (1:2), tray temperature below design limit (42 vs. 50 °C), climate dependence, and absence of water activity (aw) analysis for safety certification.

5.5 Future work

The following research lines are proposed: (a) scaling the prototype to 1:1 to validate real productive capacity; (b) incorporation of phase change materials (PCM) for nocturnal thermal storage; (c) extended field trials with rural producers; (d) thermal insulation optimization to achieve $T > 50\text{ }^{\circ}\text{C}$ on trays; (e) visual manual for community replication.

Additionally, a systematic analysis of dehydration kinetics by food type is proposed, evaluating at least five categories: tropical fruits (mango, papaya, pineapple), aromatic herbs (mint, cilantro, epazote), vegetables (chili, tomato, squash), roots and tubers (sweet potato, ginger), and legumes (beans, lentils). For each category, characterizing the drying curve, determining the optimal mathematical model (Page, Henderson-Pabis, logarithmic, or Two-Term), measuring final water activity (a_w), and evaluating organoleptic property retention (color, texture, aroma) is recommended. This analysis would generate reference tables with optimal dehydration times and temperatures for each product, facilitating system adoption by rural producers without technical training.

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