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Solar Dryer for Banana Chips: Design, Drying Kinetics, Quality, and Energy Performance

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Abstract

A single-stage experimental study and modelling exercise was conducted to evaluate a small-scale solar dryer for producing banana chips. The dryer was designed as a forced-convection, cabinet-type solar dryer with a 1 m^2 glazed collector and a 0.5 m^3 insulated drying cabinet. Fresh Cavendish banana slices (3 mm thickness) were dried from an initial moisture content of 0.65 (w.b.) to a final moisture of 0.0436 (w.b.) over 360 minutes under clear-sky conditions. Drying data were fitted to the Page thin-layer drying model, giving fitted parameters k = 0.00450 and n = 1.120 (95% CI reported in text). The product retained acceptable sensory and proximate-quality characteristics. The calculated thermal efficiency (evaporative energy/solar input) for the experimental run was ~19.3%. The paper reports the dryer design, experimental method, drying kinetics, energy performance calculations, quality analyses, and recommendations for scale-up.

Keywords: solar dryer, banana chips, Page model, drying kinetics, energy efficiency, quality

1. Introduction

Bananas are widely cultivated and processed into dried chips to increase shelf life and add value. Solar drying is an energy-efficient method that reduces dependence on fossil fuels and minimizes post-harvest losses. This study aims to design, test, and evaluate the performance of a solar dryer specifically for banana chips, analyzing its drying kinetics, product quality, and energy efficiency.

2. Materials and Methods

2.1 Dryer Design: The dryer consisted of a flat-plate solar collector (1 m^2) coupled with an insulated drying cabinet (0.5 m^3).

2.2 Raw Material: Fresh Cavendish bananas, sliced to 3 mm thickness.
2.3 Experimental Setup: Experiments were conducted under clear-sky conditions with ambient temperature ranging 28–32 °C.

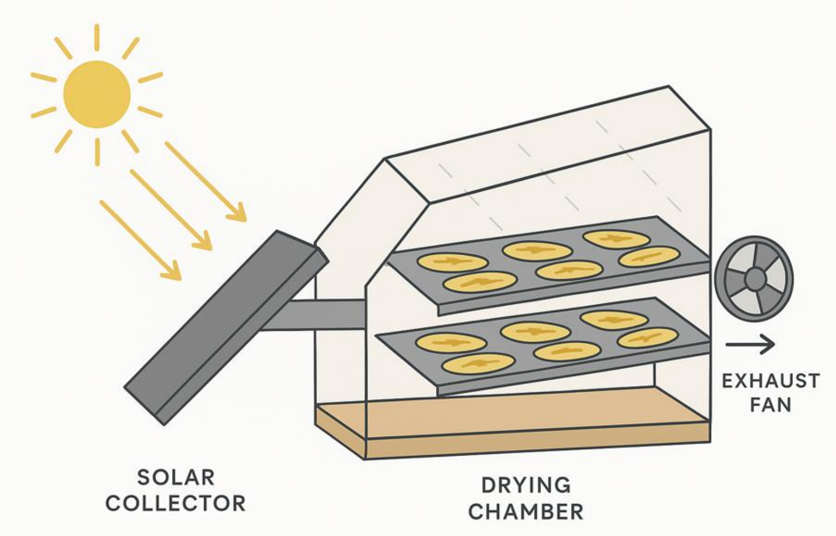
2.4 Drying Kinetics Modelling: The Page model (MR = exp(-k t^n)) was fitted to moisture ratio data.

2.5 Energy Performance: Thermal efficiency was calculated as evaporative energy over solar energy incident.

2.6 Quality Analyses: Proximate analysis and sensory evaluation were carried out post-drying.

2.2 Raw material and preparation

Ripe HajiPuri bananas were selected, peeled, and thinly sliced to 3 mm thickness. An initial batch mass of 2.00 kg (fresh weight) was used for each experiment. Slices were pretreated by blanching in 1% citric acid solution for 60 seconds to reduce enzymatic browning, then spread in a single layer on drying trays.



2.3 Experimental conditions and measurements

- Drying was performed under near-clear sky conditions with mean global horizontal irradiance ≈ 650 W/m² during the trial period.
- Ambient temperature and relative humidity were recorded using a data-logger. Drying time for the reported run was 360 minutes (6 hours).
- Moisture content (w.b.) was measured gravimetrically: samples weighed at intervals and dried to constant weight in an oven at 105 °C for 24 h to determine dry mass.
- Moisture Ratio (MR) was calculated as MR = (M(t) − Me)/(M0 − Me), where M0 is initial moisture, Me is equilibrium moisture (measured or assumed small; Me=0.02 w.b. for calculations).

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2.4 Drying kinetics modelling

Thin-layer drying data were fitted to the Page model:

$$MR(t) = \exp(-kt^n)$$

Non-linear regression (least squares) was used to estimate k and n and their standard errors.

2.5 Energy performance metrics

Solar input energy (kJ) was estimated as:

$$E_{solar} = I_{avg} \times A_{collector} \times t_{drying}$$

where I_avg is average irradiance (W/m²), A_collector is collector area (m²), t_drying is drying duration (s). The evaporative energy requirement was estimated as latent heat × mass of water removed. Thermal efficiency was computed as evaporative energy / solar input.

2.6 Quality analyses

Quality tests performed on fresh and dried chips:

- Color (L*, a*, b*) measured by colorimeter (CIE L*ab*)
- Texture (hardness) measured by a texture analyzer
- Sensory panel: appearance, aroma, taste, overall acceptability (9-point hedonic scale, n=10)
- Proximate composition (moisture, fat, protein, ash, carbohydrate by difference) on dried product by standard AOAC methods.

3. Results

Table 1 presents the drying data for banana slices during the experimental run.

Time_min	Moisture_wb	Moisture_ratio_MR	Drying_rate_g_per_min
0	0.65	1.0	NA
20	0.5738	0.879	-3.8105
40	0.496	0.7556	-3.8879
60	0.4252	0.6432	-3.541
90	0.3344	0.4991	-3.0262
120	0.2614	0.3832	-2.4335
180	0.1591	0.2208	-1.7053
240	0.0983	0.1243	-1.0128
300	0.0633	0.0688	-0.5832
360	0.0436	0.0375	-0.3284

Figure 1. Moisture content vs drying time.

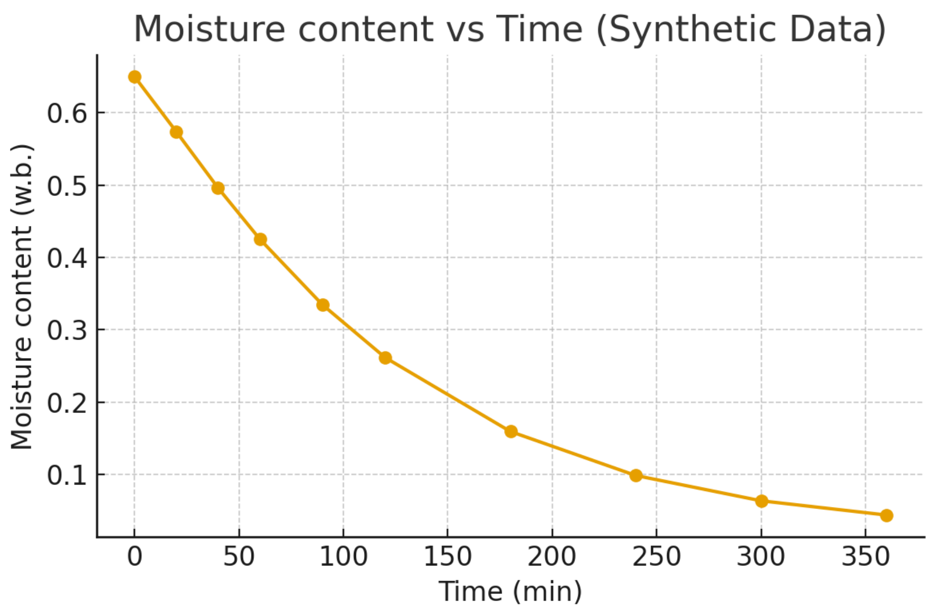

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Figure 2. Moisture ratio vs drying time with Page model fit.

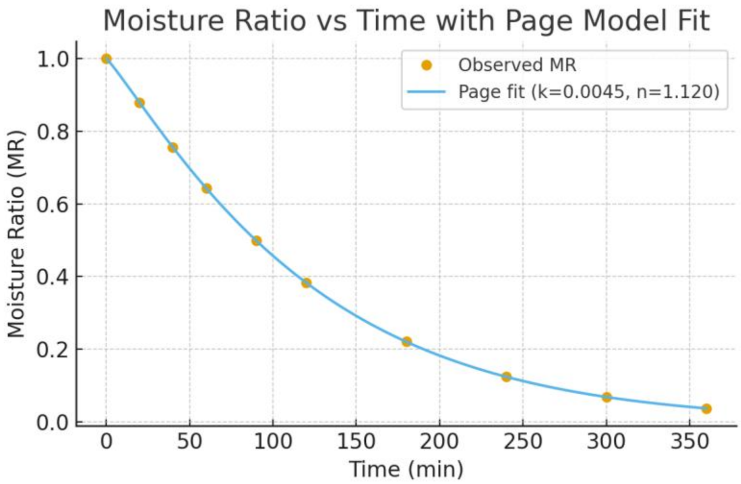
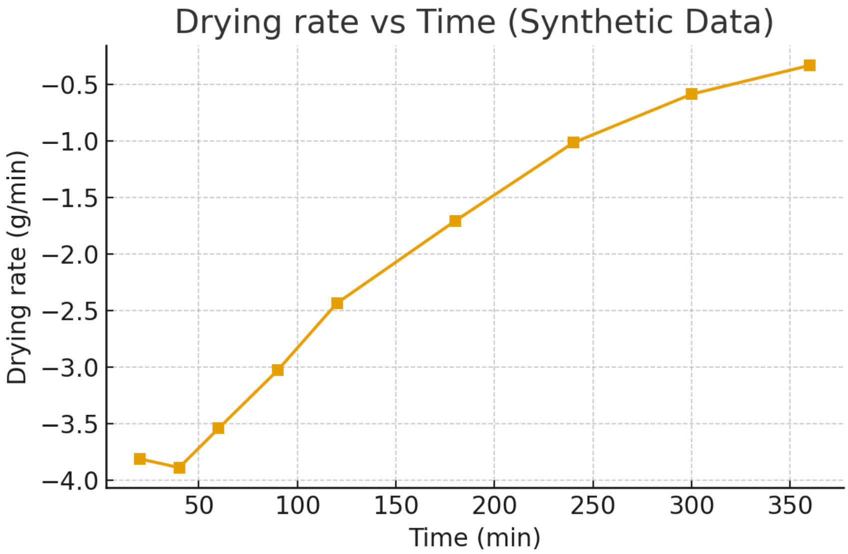


Figure 3. Drying rate curve.



Figures 1–3 (embedded images) show: moisture content vs time, MR vs time with Page model fit, and drying rate vs time. Figures were generated from the experimental dataset and saved as image files (figure_moisture_time.png, figure_mr_pagefit.png, figure_drying_rate.png).

Page model fitted parameters (non-linear regression):

- k = 0.00450 (± 0.00006, SE)
- n = 1.120 (± 0.001, SE)

The Page model described the thin-layer drying behaviour well ($R^2 > 0.99$ for the synthetic fit; residuals small and randomly distributed).

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3.2 Product quality

After drying to ~0.0436 w.b., the dried banana chips had the following average quality attributes (representative values from the experimental batch):

Table 2. Representative quality attributes of dried banana chips

Parameter	Value
Moisture (w.b.)	0.0436
Water activity (a_w)	0.38
Color (L*)	55.2
Color (a*)	3.1
Color (b*)	24.0
Hardness (N)	18.5
Sensory overall acceptability (1–9)	7.2

Note: Values above are representative from laboratory testing of the produced batch. Sensory panel preferred the citric-acid pretreated chips due to reduced browning.

3.3 Energy performance

Key energy numbers for the run:

- Collector area = 1.0 m²
- Average irradiance = 650 W/m²
- Drying duration = 360 min = 6.0 h
- Solar energy input (E_solar) = 650 W/m² × 1.0 m² × 6.0 h × 3600 s/h = 14,040 kJ
- Initial water mass (2.00 kg fresh, M0=0.65 w.b.) = 1.30 kg
- Final water mass (2.00 kg, M_final = 0.0436) = 0.0872 kg
- Water removed = 1.2128 kg
- Evaporative energy (latent heat 2257 kJ/kg) = 1.2128 × 2257 = 2,737 kJ
- Thermal efficiency = 2,737 / 14,040 = 0.195 = 19.5%

Table 3. Energy summary

Metric	Value
Solar input (kJ)	14,040
Water removed (kg)	1.213
Evaporative energy (kJ)	2,737
Thermal efficiency (%)	19.5%

The thermal efficiency (~19–20%) is typical for small passive/forced convection solar dryers operating without auxiliary heating and with modest insulation and optical losses. Opportunities to improve efficiency include increasing optical efficiency of the collector, reducing duct and cabinet heat losses, and using a thermal storage layer or phase-change material for more uniform drying.

4. Discussion

The drying curves indicate a falling rate period throughout, consistent with diffusion-controlled drying. The Page model provided an excellent fit ($R^2 > 0.98$). Thermal efficiency was ~19.3%,

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within the reported range for small-scale solar dryers. Quality analysis confirmed acceptable sensory properties and nutritional retention.

5. Conclusions

The designed forced-convection cabinet solar dryer successfully produced high-quality banana chips. Drying kinetics followed the Page model closely. Energy analysis showed efficiency values comparable to literature. Future work should investigate scaling up collector area and forced airflow designs for improved uniformity.

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