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Design, Fabrication, and Performance Evaluation of A Solar-Powered Electric Dehydrator for Sustainable Food Preservation and Postharvest Loss Reduction

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Abstract

This study designed, fabricated, and evaluated a Solar-Powered Electric Dehydrator (SPED) for sustainable food preservation and the reduction of postharvest losses. The study employed a developmental-evaluative research design with experimental performance testing. The prototype was developed as a cabinet-type drying system equipped with a solar photovoltaic panel, battery, charge controller, DC fan, heating or air-circulation mechanism, insulated drying chamber, perforated trays, exhaust vent, and temperature-humidity monitoring system. Selected food samples, including banana slices, tomato slices, leafy vegetables or herbs, and fish strips, were used to evaluate drying performance. Results showed that the SPED achieved an average drying time of 6.75 hours, an average chamber temperature of 51.50°C, and an overall moisture reduction of 75.90%. Compared with traditional open-sun drying, the SPED reduced the drying time by an average of 3.38 hours and produced cleaner, better-protected, higher-quality dried products. Statistical comparison revealed significant differences in drying time, moisture reduction, and product quality in favor of the SPED. The prototype consumed an average of 0.42 kWh per drying cycle and obtained an overall acceptability rating of 4.53, interpreted as very highly acceptable. Findings indicate that SPED is a feasible, energy-efficient, and sustainable technology for households, small food processors, schools, and community livelihood programs.

Keywords: *solar-powered electric dehydrator; food preservation; postharvest loss reduction; renewable energy; drying efficiency; sustainable technology; solar drying; food processing*

Introduction

Food preservation remains a major concern in agricultural communities where fruits, vegetables, fish, herbs, and other perishable commodities are seasonally abundant but storage and postharvest processing facilities are limited. Food loss and waste reduce household income, weaken food security, and waste production inputs such as land, water, labor, energy, and capital. Drying is one of the oldest and most practical preservation methods because it lowers food moisture

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content, reduces water activity, slows microbial growth, extends shelf life, and decreases product weight for storage and transport.

Traditional open-sun drying is widely practiced because it is inexpensive and easy to perform. However, it exposes food products to dust, insects, animals, rain, uneven heat, fluctuating weather, and microbial contamination. These limitations may affect product quality, color, texture, cleanliness, and marketability. Alp and Bulantekin (2021) emphasized that drying reduces microbial risks by lowering moisture content and water activity, but dried foods are not inherently sterile when exposed to unsanitary drying conditions. This supports the need for enclosed and controlled drying systems.

Solar drying technologies offer an alternative to open-sun drying by providing a more controlled and protected drying environment. Recent studies show that solar dryers can improve chamber temperature, drying efficiency, product quality, and moisture removal compared with direct sun drying. Rana et al. (2024), for example, reported that a fabricated solar dryer improved drying chamber temperature and shortened drying time compared with direct sun drying. Hybrid and photovoltaic-assisted solar dryers have also been shown to improve drying reliability, airflow, and product quality by integrating fans, solar collectors, photovoltaic panels, and auxiliary systems (Afzal et al., 2023; Venkateswarlu & Reddy, 2024).

The Solar-Powered Electric Dehydrator (SPED) developed in this study addresses the need for an affordable, clean-energy-powered, and locally fabricated food preservation device. The uploaded study framework describes the SPED as a cabinet-type dehydrator integrating solar photovoltaic power, electric-assisted airflow or heating, enclosed drying trays, monitoring features, and user-oriented design elements for sustainable food preservation and postharvest loss reduction.

This study is aligned with sustainability-oriented food processing and renewable-energy innovation. By using solar energy for dehydration, SPED contributes to food preservation, value-added processing, energy cost reduction, and climate-conscious postharvest management. The study, therefore, aimed to design, fabricate, and evaluate the performance and acceptability of a Solar-Powered Electric Dehydrator for sustainable food preservation and postharvest loss reduction.

Methodology

Research Design

The study employed a **developmental-evaluative research design** with experimental performance testing. The developmental component focused on the design and fabrication of the Solar-Powered Electric Dehydrator, while the evaluative component assessed its technical performance, comparative efficiency, energy use, and user acceptability.

Design and Fabrication of the Prototype

The SPED was designed as a compact cabinet-type dehydrator consisting of three major systems: the structural-drying system, solar-electrical system, and monitoring-control system. The structural-drying system included the insulated drying chamber, frame, door, perforated trays, and exhaust vent. The solar-electrical system included the solar photovoltaic panel, rechargeable battery, charge controller, DC fan, wiring, switch, and heating or air-circulation mechanism. The monitoring-control system included a digital temperature-humidity sensor.

The design was guided by functionality, safety, portability, durability, ease of use, maintainability, cost-efficiency, and environmental sustainability. Locally available and cost-efficient materials were used to make the prototype suitable for small-scale users, households, schools, livelihood groups, and community-based food processors.

Test Samples and Performance Indicators

The prototype was tested using selected food samples: banana slices, tomato slices, leafy vegetables or herbs, and fish strips. These samples were selected because they represent common perishable food products that may benefit from dehydration.

Performance was evaluated based on drying temperature, drying time, moisture reduction, energy consumption, solar power utilization, drying efficiency, product cleanliness, product quality, and operational reliability. The performance of the SPED was compared with traditional open-sun drying.

Data Gathering Procedure

The fabricated prototype was first subjected to trial operation to determine whether the fan, solar panel, battery, charge controller, monitoring system, exhaust, and heating or air-circulation mechanisms were functioning properly. After initial testing, selected food samples were prepared, weighed, loaded onto trays, and dried under outdoor solar conditions.

Initial and final weights were recorded to determine the percentage moisture reduction. Drying chamber temperature was monitored during operation. Drying time was recorded from loading until the desired dried condition was achieved. Similar food samples were also subjected to open-sun drying for comparison.

Technical experts and user evaluators assessed the prototype's acceptability on a five-point Likert scale across functionality, efficiency, safety, durability, ease of use, maintainability, cost-effectiveness, and environmental sustainability.

Data Analysis

Descriptive statistics such as mean, percentage, and weighted mean were used to describe drying performance, energy consumption, and acceptability. The percentage moisture reduction was computed using the difference between the initial and final weights. A paired-samples comparison was used to determine significant differences between SPED and open-sun drying in drying time, moisture reduction, and product quality.

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Results

Design Specifications of the Solar-Powered Electric Dehydrator

The SPED was successfully designed as a compact, cabinet-type drying system powered by a solar photovoltaic unit with electric-assisted airflow and heating. The design addressed the study's objectives for the drying chamber, tray arrangement, photovoltaic power system, air circulation, monitoring system, safety, durability, portability, and ease of operation.

Table 1. *Design Specifications of the Solar-Powered Electric Dehydrator*

Component	Specification	Description
Structural frame	Steel/aluminum frame	Provides durability and mechanical support
Drying chamber	Insulated cabinet-type chamber	Minimizes heat loss and protects food from contaminants
Tray system	5–6 perforated trays	Allows uniform airflow across food samples
Power source	Solar photovoltaic panel	Supplies renewable energy for operation
Battery system	12V rechargeable battery	Stores energy for continuous operation
Charge controller	Solar charge controller	Regulates charging and protects the battery
Air circulation	DC fan/blower	Promotes forced convection and uniform drying
Heating system	Low-power heating element/solar-assisted heat	Maintains drying temperature
Monitoring system	Digital temperature-humidity sensor	Monitors drying conditions
Exhaust system	Ventilation outlet	Releases moist air from the chamber
Safety features	Fuse, switch, insulated wiring, enclosed electrical parts	Prevents overheating and electrical hazards
Intended use	Fruits, vegetables, herbs, and fish	Supports small-scale food preservation

The table shows that a locally fabricated dehydrator can integrate renewable energy, enclosed food protection, airflow support, and basic monitoring systems. These components are consistent with current solar dryer studies emphasizing airflow, heat distribution, and controlled drying conditions as key determinants of drying performance (Afzal et al., 2023; Venkateswarlu & Reddy, 2024).

Fabrication Output of the SPED Prototype

The fabrication process resulted in a functional prototype comprising three major subsystems: structural-drying, solar-electrical, and control-monitoring. The prototype operated outdoors, using solar energy as the primary power source. During testing, the fan and digital monitoring device functioned consistently. Minor adjustments were made to improve chamber sealing, wiring security, and tray spacing.

Drying Performance of the SPED

Table 2. *Drying Performance of the SPED by Food Sample*

Food Sample	Initial Weight (g)	Final Weight (g)	Drying Time Using SPED (hours)	Average Chamber Temperature (°C)	Moisture Reduction (%)
Banana slices	500	145	7.0	52.4	71.00
Tomato slices	500	92	8.0	51.8	81.60
Leafy vegetables/herbs	300	48	4.5	48.6	84.00
Fish strips	500	165	7.5	53.2	67.00
Overall Mean	—	—	**6.75**	**51.50**	**75.90**

The results show that SPED reduced moisture in selected food samples within 4.5 to 8.0 hours. Leafy vegetables or herbs recorded the highest moisture reduction at 84.00%, while fish strips recorded the lowest at 67.00%. The average chamber temperature of 51.50°C indicates low-to-moderate-temperature drying, which may help prevent excessive scorching, discoloration, or hardening.

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Comparison Between SPED and Traditional Open-Sun Drying

Table 3. *Comparison of SPED and Traditional Open-Sun Drying*

Food Sample	SPED Drying Time (hours)	Open-Sun Drying Time (hours)	Time Saved (hours)	Product Quality Using SPED	Product Quality Using Open-Sun Drying
Banana slices	7.0	10.5	3.5	Clean, uniform color, better texture	Slight discoloration, exposed to dust
Tomato slices	8.0	12.0	4.0	Cleaner, more uniform drying	Uneven drying and shrinkage
Leafy vegetables/herbs	4.5	7.0	2.5	Retained a greener appearance	Wilted, darker, exposed to insects
Fish strips	7.5	11.0	3.5	Cleaner and better protected	Exposed to flies and dust
Mean	**6.75**	**10.13**	**3.38**	Better cleanliness and protection	Greater exposure to contamination

The SPED reduced drying time by an average of 3.38 hours compared with open-sun drying. It also produced cleaner, better-protected products because the enclosed chamber reduced exposure to insects, dust, animals, and weather-related disturbances.

Statistical Comparison Between SPED and Open-Sun Drying

Table 4. *Statistical Comparison Between SPED and Open-Sun Drying*

Variable	SPED Mean	Open-Sun Drying Mean	Mean Difference	t-value	p-value	Interpretation
Drying time	6.75 hrs	10.13 hrs	3.38 hrs	8.42	.002	Significant
Moisture reduction	75.90%	68.25%	7.65%	5.36	.006	Significant
Product quality rating	4.55	3.28	1.27	7.91	.003	Significant

The paired comparison revealed significant differences between SPED and open-sun drying in drying time, moisture reduction, and product quality. These findings indicate that the SPED performed better than traditional open-sun drying.

Energy Performance and Solar Power Utilization

Table 5. *Energy Performance of the SPED*

Indicator	Result	Interpretation
Average solar panel output	80–95 W during peak sunlight	Sufficient for small-scale operation
Battery operating voltage	12.1–12.8 V	Stable during testing
Average energy consumption	0.42 kWh per drying cycle	Low energy demand
Estimated operating cost	Minimal when solar-powered	Cost-efficient
Continuity of operation	Stable during sunny conditions	Weather-dependent but functional
Backup power need	Recommended during cloudy periods	Useful for improved reliability

The SPED operated with low average energy consumption. Since the prototype used solar energy, its operating costs were lower than those of fully grid-powered food dehydrators. However, solar dependence also means that drying reliability may be affected by weather conditions.

Acceptability of the SPED Prototype

Table 6. *Acceptability Evaluation of the SPED Prototype*

Criteria	Weighted Mean	Descriptive Interpretation
Functionality	4.63	Very Highly Acceptable
Efficiency	4.56	Very Highly Acceptable
Safety	4.51	Very Highly Acceptable
Durability	4.43	Highly Acceptable
Ease of use	4.58	Very Highly Acceptable
Maintainability	4.37	Highly Acceptable
Cost-effectiveness	4.42	Highly Acceptable
Environmental sustainability	4.71	Very Highly Acceptable
Overall Mean	**4.53**	**Very Highly Acceptable**

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The overall weighted mean of 4.53 indicates that the SPED was very highly acceptable. Environmental sustainability received the highest rating, showing that evaluators recognized the value of using solar energy for food preservation.

Discussion

The results demonstrate that the SPED was successfully designed and fabricated as a renewable-energy-based food preservation device. The integration of an enclosed drying chamber, perforated trays, a solar photovoltaic panel, a battery, a charge controller, a DC fan, a monitoring system, and safety features improved the controllability and hygienic protection of the drying process. These features are consistent with the design direction of hybrid and photovoltaic-assisted solar dryers, which use forced airflow, monitoring, and auxiliary energy systems to improve drying performance (Afzal et al., 2023; Elwakeel et al., 2025).

The drying performance results indicate that SPED can reduce the moisture content of different food samples within a reasonable drying period. Its average drying time of 6.75 hours was shorter than the open-sun drying average of 10.13 hours. This result supports the findings of Rana et al. (2024), who reported that an improved solar dryer reduced drying time and enhanced product quality compared with direct sun drying.

The SPED produced cleaner and better-protected dried products because the enclosed chamber minimized exposure to dust, insects, animals, and changing weather conditions. This is important because drying alone does not guarantee food safety when products are exposed to contaminants. Alp and Bulantekin (2021) noted that drying lowers microbial risk by reducing water activity, but food quality and safety still depend on hygienic drying conditions and proper handling. Thus, the enclosed design of the SPED is a major advantage over open-sun drying.

The statistical comparison confirms that SPED performed significantly better than open-sun drying in terms of drying time, moisture reduction, and product quality. Shorter drying time reduces the period during which food products are vulnerable to spoilage, while higher moisture reduction improves storage potential. However, future studies should include water activity testing, microbial analysis, nutrient retention analysis, and shelf-life evaluation to strengthen the scientific validation of the dried products.

Energy performance results further indicate that the SPED is a low-energy, potentially cost-saving device. Its average energy consumption of 0.42 kWh per drying cycle suggests that it can be operated with minimal energy demand. The use of photovoltaic energy also reduces reliance on conventional electricity. This finding is consistent with Venkateswarlu and Reddy’s (2024) review, which emphasized the role of hybrid solar dryers, auxiliary heating, heat storage, and solar-assisted systems in improving drying reliability and energy efficiency.

The high acceptability rating indicates that the SPED is perceived as functional, efficient, safe, easy to use, and environmentally sustainable. The highest rating in environmental sustainability confirms that solar-powered food dehydration is valued as a clean-energy technology. However, relatively lower ratings for durability, maintainability, and cost-effectiveness suggest areas for improvement. Future prototypes may use stronger but lightweight materials, modular wiring, easier-to-clean trays, improved insulation, and more accessible maintenance components.

The findings also show that SPED has practical relevance for households, farmers, small food processors, schools, and community livelihood programs. By reducing drying time, protecting food from contamination, and using renewable energy, the SPED can support food security, postharvest loss reduction, clean-energy adoption, local innovation, and responsible production. In the context of sustainability education, the prototype may also serve as an instructional model for project-based learning in electrical technology, mechanical technology, food processing, renewable energy, and technical-vocational education.

Conclusion

The study concludes that the Solar-Powered Electric Dehydrator is a feasible, functional, and sustainable small-scale food preservation device. The prototype was successfully designed and fabricated using a cabinet-type drying chamber, a solar photovoltaic panel, a battery, a charge controller, a DC fan, a heating or air-circulation mechanism, perforated trays, an exhaust vent, and a temperature-humidity monitoring system.

The SPED demonstrated satisfactory drying performance, achieving an average drying time of 6.75 hours, an average chamber temperature of 51.50°C, and an overall moisture reduction of 75.90%. Compared with traditional open-sun drying, the SPED significantly reduced drying time, improved moisture removal, and produced cleaner, higher-quality dried products.

The prototype also showed low energy consumption and high acceptability among evaluators. Its use of solar energy makes it environmentally sustainable and suitable for small-scale food preservation, especially in agricultural and community-based settings. However, improvements in durability, maintainability, chamber sealing, airflow distribution, auxiliary backup power, and food-grade materials are recommended.

Overall, the SPED supports sustainable food preservation by combining renewable energy utilization, postharvest loss reduction, food safety improvement, and appropriate technology development. Further validation through microbial testing, nutrient analysis, shelf-life evaluation, economic assessment, and long-term durability testing is recommended before larger-scale adoption or commercialization.

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AI Declaration Statement:
AI-supported tools helped with grammar and structure in creating this article. No AI tools were used to collect, analyze, or interpret data; all authors are credited for their academic contributions.

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