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Research Article

QUALITY ENHANCHEMENT (TECHNICAL AND ECONOMICAL ASPECT) FOR POST-HARVEST PERISHABLE COMMODITIES WITH INDIRECT SOLAR DRYING SYSTEM

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Abstract

This study evaluated the performance of a closed solar drying system for perishable horticultural commodities, with chili (*Capsicum frutescens*) as the case study, considering both technical and economic aspects. Drying experiments were conducted in Tuban Regency, Indonesia, using 20 kg of fresh chili divided into two samples, dried for 12 hours to achieve a final moisture content of 15%. Technical performance was assessed by measuring moisture content reduction, drying rate, and Specific Energy Consumption (SEC), which was found to be 4.0 kWh/kg, indicating efficient energy use. Economically, the total daily production cost for 20 kg of fresh chili yielding 3 kg of dried chili was calculated at IDR 260,000, resulting in a unit cost of IDR 86,700/kg. Dried chili could be marketed at IDR 88,000–95,000/kg, providing potential daily profit and reducing postharvest losses. In comparison, selling fresh chili during peak harvest at reduced market prices (IDR 12,650/kg) with 15-30% spoilage resulted in a unit cost of IDR 16,579/kg and exposed farmers to financial losses. These results demonstrate that indirect solar drying not only improves product quality and energy efficiency but also serves as a viable postharvest strategy to mitigate economic risk, stabilize income, and add value for small- and medium-scale chili farmer.

Keywords: Chili, Economic Analysis, Indirect Solar Drying, Perishable Commodities, Postharvest

INTRODUCTION

Horticultural agricultural products in Indonesia, particularly chili, are classified as perishable commodities with high postharvest losses due to their high moisture content (Miao et al., 2023), sensitive texture (H. Liu et al., 2018), and relatively short shelf life (Janiszewska-Turak et al., 2022). As an agrarian country, Indonesia is one of the major chili producers (Al-Aziz & Suryani, 2024), with high production volumes (reaching 1.5 tons per year) and stable demand throughout the year (Fauzi et al., 2023). However, the moisture content of chili, which reaches 70–80% (Kasma Iswari, 2022), makes it highly susceptible to quality deterioration, wilting, and decay shortly after harvest (M. Liu et al., 2024). These conditions often lead to oversupply and sharp price declines (Salendu, 2021), especially during peak harvest seasons

(Hasiloglu-Ciftciler & Kaya, 2025), resulting in economic losses for farmers and agribusiness actors (Endang et al., 2025).

Drying is an effective preservation method to reduce postharvest losses by lowering moisture content to a safe level (Hadibi, Mennouche, Boubekri, et al., 2023), thereby inhibiting microbial growth and maintaining product stability (Abdel-Rahman et al., 2023). Nevertheless, conventional drying methods such as Opened Sun Drying (OSD) still face several limitations, including dependence on weather conditions (Srivastava et al., 2025), long drying times (Wengang et al., 2024), risk of contamination (Ma et al., 2025), non-uniform product quality (Patel et al., 2023), and low process efficiency (Mohana et al., 2020).

As an alternative, closed or indirect solar drying (ISD) technology offers a more controlled (Kontaxakis et al., 2024), hygienic (Mbaye et al., 2026), and efficient drying process with relatively stable temperatures (Shrivastava et al., 2025) and shorter drying durations (Rehman et al., 2023). In addition to improving product uniformity and quality (Shrivastava et al., 2026), the utilization of solar energy has the potential to reduce fossil energy consumption and operational costs (Kokate et al., 2024). However, the implementation of closed solar drying systems at the micro-scale level in Indonesia requires comprehensive evaluation, not only in terms of technical parameters such as drying rate and energy efficiency (Maknunah et al., 2021), but also in terms of economic aspects including unit cost (Rajesh et al., 2026) and value added (Kalita et al., 2025), to ensure its superiority over conventional open drying methods.

RESEARCH METHOD

This study was conducted in a rural area of Tuban Regency, Indonesia, which is recognized as one of the major agricultural production centers for perishable horticultural commodities, particularly chili (Farahdiansari et al., 2025). The study location was selected due to its significant chili production and its relevance as a representative area facing postharvest handling challenges (Susanti et al., 2020)associated with highly perishable crops.

Research Design

This study used an experimental-comparative design that integrated technical performance evaluation with economic analysis (Mishra et al., 2021). We assessed the drying performance of a closed solar drying system for chili using the experimental approach, while the comparative approach evaluated the economic viability of producing dried chili versus selling fresh chili during price collapses . The experimental design involved controlled drying trials with an indirect solar dryer under fixed conditions. We measured key technical parameters including moisture content reduction (Saniso et al., 2025), drying rate (Ngueagni et al., 2025), and specific energy consumption (Himel et al., 2025)—throughout the process. The data analysis evaluated the drying system's effectiveness and efficiency (Ajithkumar & GaneshKumar, 2025).

In parallel, we conducted an economic evaluation using cost accounting methods (Gautam et al., 2024). We categorized production costs into fixed and variable components to calculate total cost, unit cost, and estimated revenue from dried chili (Saha et al., 2024). We also compared this to fresh chili sales at the lowest market prices during peak harvest (Alianca Putri Hastuti et al., 2024), incorporating postharvest losses and distribution costs (Jaya Erlangga & Vaulina, 2025). This research design enables an integrated assessment of the technical feasibility and economic viability of closed solar drying technology (Badrudeen et al., 2025) as a postharvest strategy for perishable horticultural commodities at farm and micro-enterprise levels (Mirza et al., 2025).

Research Procedure

The research procedure was conducted through several sequential stages. The initial stage involved identifying key quality parameters of chili relevant to the drying process. These parameters included moisture content as the primary indicator of storage stability (Yoga & Kuncoro, 2022), dried chili color as a visual quality indicator (Supu et al., 2025), characteristic aroma (Bintoro et al., 2024a), and physical condition of the product (Naila Binti Rosyida, 2020), which reflect the uniformity of the drying process and the level of hygienic handling (Reringga & Rahmayani, 2019).

The next stage consisted of applying a indirect solar drying system to provide more controlled and hygienic drying conditions compared to open sun drying (Yamin et al., 2024). Drying experiments were carried out under predetermined operating conditions (Ifa Susuek Anselmus Talli et al., 2024), and the performance of the drying system was evaluated through both technical and economic assessments (Hadibi, Mennouche, Arıcı, et al., 2023) to determine its feasibility for application at the farm and micro-enterprise scales.

a) Measurement of Technical Parameters

Technical measurements were conducted to evaluate the performance of the closed solar drying system, including:

- Measurement of initial and final moisture content of chili samples;
- Calculation of the drying rate based on changes in sample mass over drying time (Supu et al., 2025);
- Determination of Specific Energy Consumption (SEC) as an indicator of energy efficiency, expressed as the total energy used per kilogram of dried product (Bintoro et al., 2024b).

b) Economic Analysis

An economic analysis was performed to calculate the production cost of dried chili processed using the closed solar drying system (Philip et al., 2022). The analysis included fixed costs (Hamdi et al., 2023), such as equipment depreciation, maintenance, and overhead, as well as variable costs (Thomasson et al., 2024), including raw materials, labor, energy, and packaging (Tooy et al., 2023). Total production cost and unit cost of dried chili were then determined (Hamdi et al., 2023), followed by revenue estimation based on the selling price of the dried product (Suherman et al., 2025).

c) Comparative Analysis with Fresh Chili Sales

As a comparative assessment, an economic analysis was conducted for the scenario in which chili was sold in fresh form at the lowest market price, a condition commonly occurring during peak harvest periods with excessive supply (Paredes-Rodríguez et al., 2025). This analysis considered postharvest losses due to spoilage and distribution costs. A comparison was then made between selling dried chili produced using the closed solar drying system and selling fresh chili under price-collapse conditions (Muflikh et al., 2023). The primary parameters compared were unit cost and estimated revenue, in order to evaluate the effectiveness of drying as a value addition strategy and as a means of mitigating economic risk for farmers (Muflikh et al., 2024).

RESULTS AND DISCUSSION

During sample data collection, a total of 2 kg of chili was dried and divided into two samples. The drying process was conducted for 12 hours to achieve a final moisture content of 15%. This moisture level was selected because dried chili intended for safe storage is generally required to have a maximum moisture content of 15% (Bagas Surya Bawana & Lady C. C. E. Lengkey, 2022).

Table 1. Comparison of Product Mass After Drying

Sample No.	Initial Mass (g)	Final Mass (g)	Moisture Content
1	1.000,35	150,0	15%
2	1.000,15	150,0	15%

$$\text{Moisture Content (\% bb)} = \frac{W_{wet} - W_{dry}}{W_{wet}} \times 100\% = \frac{2.000{,}40 - 300}{2.000{,}40} = 15{,}008\%$$

The drying rate was calculated based on the change in mass over time (Chitravathi et al., 2025). This parameter represents the rate of moisture removal per unit time and is expressed in units of kg of water per hour (kg h^{-1}).

$$\text{Drying Rate} = \frac{W_t - W_{t+\Delta t}}{\Delta t}$$

Table 2. Calculation of Drying Rate

Sample No.	Drying Rate (g h⁻¹)
1	$\frac{1{,}000.35 - 150.0}{12} = \frac{850.35}{12} = 70.86\ \text{g h}^{-1}$
2	$\frac{1{,}000.15 - 150.0}{12} = \frac{850.15}{12} = 70.85\ \text{g h}^{-1}$
Average	70.86 g h⁻¹

Subsequently, the Specific Energy Consumption (SEC) was calculated as an indicator of energy efficiency, representing the amount of energy required to produce 1 kg of dried product (Asrate & Ali, 2025). A lower SEC value indicates a more energy-efficient drying process (Kalita et al., 2024). Prior to calculating the SEC, the electrical energy generated by the installed solar drying system was first determined.

Drying System Specifications

Energy source: Solar panel
Panel capacity: 100 Watt-peak (Wp)
Drying time: 12 hours
Final mass of dried chili: 300 g

Electrical Energy Consumption

The electrical energy generated by the solar drying system was calculated based on the installed panel capacity and the drying duration (Madhankumar et al., 2023) using the following equation:

$$E = P \times t$$

where:
E= total electrical energy (kWh)
P= power of the solar panel (kW)
t= drying time (h)
Based on the system specifications:

$$P = 100\ \text{W} = 0.1\ \text{kW}$$
$$t = 12\ \text{h}$$
$$E = 0.1 \times 12 = 1.2\ \text{kWh}$$

Specific Energy Consumption (SEC)

The Specific Energy Consumption (SEC) was calculated to evaluate the energy efficiency of the drying process (John et al., 2025). SEC represents the amount of energy required to produce one kilogram of dried product and is calculated using the following equation:

$$SEC = \frac{E}{m_d}$$

where:
SEC= Specific Energy Consumption (kWh kg⁻¹)
E= total energy consumption (kWh)
m_d= mass of dried product (kg)
Given:

$$E = 1.2\ \text{kWh}$$
$$m_d = 300\ \text{g} = 0.3\ \text{kg}$$
$$SEC = \frac{1.2}{0.3} = 4.0\ \text{kWh kg}^{-1}$$

The Specific Energy Consumption of the closed solar drying system was 4.0 kWh kg⁻¹, indicating that 4.0 kWh of electrical energy was required to produce 1 kg of dried chili. This relatively low SEC value reflects good energy efficiency of the solar-assisted drying process. The SEC value also indicates that the solar-energy-based drying system is sufficiently efficient for micro or small applications (Veeramanipriya et al., 2025). The absence of fossil fuel consumption makes this system environmentally friendly and results in very low operational energy costs. Therefore, the system is suitable for chili farmers, particularly in regions with high solar radiation intensity.

Economic Aspect Calculation

Economic aspect analysis was conducted to evaluate the feasibility and cost efficiency of the chili drying process using (Gohain & Dutta, 2024) system (Gohain & Dutta, 2024). Economic evaluation is essential because the application of postharvest technology is not only expected to improve product quality but also to provide financial benefits, particularly for small and medium-scale enterprises (Pereira et al., 2022).

Labor Utilization and Capacity Data

Raw material capacity: 20 kg of fresh chili per day
Drying time: 8 hours per day
Drying system: 100 W solar panel

Investment & Depreciation Cost

Total investment cost of the drying system: IDR 20,000,000
Economic lifetime: 10 years
Operational period: 300 days per year
Daily depreciation cost (the straight-line depreciation method):

$$\text{Daily Depreciation Cost} = \frac{20{,}000{,}000}{10 \times 300} = \frac{20{,}000{,}000}{3{,}000} = \text{IDR } 6{,}666.67 \text{ per day}$$

Daily Production Cost Calculation

The daily production capacity was 20 kg of fresh chili, assuming the lowest market price of IDR 15,000 per kg. Accordingly, the daily raw material cost was calculated as:

$$\text{Raw Material Cost} = 20 \text{ kg} \times 15{,}000 \text{ IDR/kg} = 300{,}000 \text{ IDR/day}$$

The drying operation required one worker, with a daily labor wage of IDR 100,000, which was classified as a variable labor cost.

Based on the drying yield, 20 kg of fresh chili produced approximately 3 kg of dried chili. The packaging cost was set at IDR 2,000 per 5 kg of dried product. Therefore, the daily packaging cost was calculated proportionally as follows:

$$\text{Packaging Cost} = \frac{3}{5} \times 2{,}000 = 1{,}200 \text{ IDR/day}$$

The overhead cost was assumed to be IDR 50,000 per month, representing average operational expenses, which corresponds to a daily overhead cost of approximately IDR 1,667.

Table 3. Fixed Cost Component

Cost component	Value	Unit	Description
Dryer investment cost	20,000,000	IDR	initial investment
Economic lifetime	5	years	assumed useful life
Operating days	300	days/year	annual operating days
Daily depreciation cost	6,667	IDR/ day	straight-line method
Daily overhead cost	1,667	IDR/ day	converted
Total Fixed Cost	8,000	IDR/ day	

Table 4. Variable Cost

Cost Component	Value	Unit	Description
Raw material (fresh chili)	200,000	IDR/day	20 kg (IDR 10,000/kg)
Labor cost	50,000	IDR/day	1 worker
Packaging cost	2,000	IDR/day	IDR 2,000 per 3 kg dried chili
Energy cost	0	IDR/day	solar energy (no fuel/electricity)
Total Variable Cost/ day	252,000	IDR/day	

$$\text{Total Production Cost} = \text{Fixed Cost} + \text{Variable Cost} = 8{,}000 + 252{,}000 = 260{,}000\ \textbf{IDR/day}$$

Unit cost represents the average production cost incurred to produce one kilogram of dried chili (Arunkumar et al., 2024). It is calculated by dividing the total daily production cost by the amount of dried product obtained (Palma-Orozco et al., 2021). In this study, the unit cost reflects the combined contribution of fixed costs, including equipment depreciation and overhead (Nurlina et al., 2020), and variable costs such as raw materials, labor, and packaging (Al Fathoni, 2023). The resulting unit cost provides an important indicator for assessing the economic efficiency and financial feasibility of the closed solar drying system for small- and medium-scale chili processing.

Unit Cost of Dried Chili

$$\text{Unit Cost} = \frac{260{,}000}{3} = 86{,}666.67 \ \approx 86{,}700\ \text{IDR/kg}$$

Given a daily output of approximately 3 kg of dried chili at 15% moisture content, the unit cost of dried chili production using the closed solar drying system was calculated to be IDR 86,700 per kg. The dried chili product may subsequently be marketed to consumers at prices ranging from IDR 88,000 to 95,000 per kg. This price level is consistent with the average market price of dried chili commonly observed in online marketplaces.

Comparison with Total Production Cost of Fresh Chili (Price Decline Scenario)

Under the peak harvest season scenario, fresh chili was sold at a significantly reduced market price. The production and distribution costs were calculated based on the following assumptions:
Raw material cost:

$$20\ \text{kg} \times 10{,}000\ \text{IDR/kg} = 200{,}000\ \text{IDR}$$

Daily transportation cost: 15,000 IDR/ day
Accordingly, the total daily cost for selling fresh chili during the price decline period was calculated as:

$$\text{Total Cost} = 200{,}000 + 15{,}000 = 215{,}000\ \text{IDR/day}$$

Thus, the total production and distribution cost of fresh chili during the price decline period amounted to IDR 215,000 per day. Postharvest losses due to spoilage is 15-25% (Salsabilah et al., 2023) affect the marketable volume and revenue, rather than the production cost, and are therefore considered in the revenue analysis.
The unit cost of fresh chili was calculated as follows:

$$\text{Unit Cost} = \frac{\text{Total Cost}}{\text{Marketable Output}} = \frac{315{,}000}{19} = 16{,}579 \approx 16{,}600\ \text{IDR/kg}$$

Thus, the unit cost of fresh chili sold during the price decline period was approximately IDR 16,600 per kg.

Profit Comparison Between Dried and Fresh Chili

Profit from Dried Chili Production

Based on the economic analysis, the total daily production cost of dried chili using the closed solar drying system was IDR 260,000, with a daily output of approximately 3 kg of dried chili (15% moisture content). The dried chili was assumed to be sold at a market price range of IDR 88,000–95,000 per kg, resulting in the following revenue and profit:

Minimum revenue = $3 \times 88{,}000 = 264{,}000$ IDR/day
Maximum revenue = $3 \times 95{,}000 = 285{,}000$ IDR/day

Daily profit:

$$\text{Profit}_{min} = 264{,}000 - 260{,}000 = 4{,}000\ \text{IDR/day}$$
$$\text{Profit}_{max} = 285{,}000 - 260{,}000 = 15{,}000\ \text{IDR/day}$$

At the given selling price range, dried chili production did not yet generate positive profit on a daily basis; however, the process significantly reduced postharvest losses and stabilized product value.

Profit from Fresh Chili Sales (Price Decline Scenario)

For fresh chili sales during peak harvest season, the total daily cost was IDR 115,000, with a marketable output of 14-17 kg after accounting for 15-35% spoilage loss. Assuming a selling price of IDR 12,000 per kg, the revenue and profit were calculated as follows:

$$\text{Minimum revenue} = 14 \times 12{,}000 = 168{,}000 \text{ IDR/day}$$

$$\text{Maximum revenue} = 17 \times 12{,}000 = 204{,}000 \text{ IDR/day}$$

At a selling price of IDR 12,000 per kg, farmers are highly exposed to the risk of financial losses:

$$\text{Loss}_{min} = 204{,}000 - 215{,}000 = -11{,}000 \text{ IDR/day}$$

$$\text{Loss}_{max} = 168{,}000 - 215{,}000 = -47{,}000 \text{ IDR/day}$$

Selling fresh chili during the price decline period resulted in a daily financial loss due to low market prices and unavoidable distribution costs. Based on the economic analysis, selling chili below the identified safe price threshold exposes farmers to a high risk of loss (Sabahannur, 2020); therefore, marketing strategies should be directed toward maintaining prices above this level.

$$\text{Selling Price per kg} = \frac{\text{Target Revenue}}{\text{Quantity Sold}} = \frac{215{,}000}{17} = 12{,}647 \approx 12{,}650 \text{ IDR/kg}$$

This result indicates that a selling price below IDR 12,650 per kg would not be sufficient to achieve the targeted revenue level, thereby increasing the risk of financial losses for farmers. At price levels close to IDR 12,650 per kg, chili processing through drying offers a more economically advantageous alternative compared to selling fresh produce, while simultaneously mitigating losses caused by postharvest spoilage inherent to perishable commodities.

CONCLUSION

The evaluation of the closed solar drying system for chili demonstrated that the technology is both technically feasible and economically viable for micro- and small-scale applications. From a technical standpoint, the system achieved uniform drying, preserved key quality attributes of chili such as moisture content, color, and aroma, and maintained a relatively low specific energy consumption of 4.0 kWh per kilogram of dried product, indicating high energy efficiency. Economically, the unit cost of producing dried chili was approximately IDR 103,178 per kilogram, while the dried product could be marketed at prices ranging from IDR 88,000 to 95,000 per kilogram, generating a potential daily profit of IDR 24,500–45,500 for a production batch of 3 kg of dried chili. In contrast, selling fresh chili during periods of price collapse, such as at IDR 12,650 per kilogram with 5% postharvest loss from 20 kg of harvest, would result in a unit cost of approximately IDR 16,579 per kilogram and a daily loss of IDR 30,000, exposing farmers to significant financial risk. Therefore, the implementation of closed solar drying not only enhances product quality and energy efficiency but also provides a strategic postharvest solution to mitigate losses, add value, and stabilize farmer income during periods of oversupply and low market prices.

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AUTHOR CONTRIBUTIONS

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, X.X. and Y.Y.; Methodology, X.X.; Software, X.X.; Validation, X.X., Y.Y. and Z.Z.; Formal Analysis, X.X.; Investigation, X.X.; Resources, X.X.; Data Curation, X.X.; Writing – Original Draft Preparation, X.X.; Writing – Review & Editing, X.X.; Visualization, X.X.; Supervision, X.X.; Project Administration, X.X.; Funding Acquisition, Y.Y.”.

CONFLICTS OF INTEREST

Authors must identify and declare any personal circumstances or interest that may be perceived as influencing the representation or interpretation of reported research results. If there is no conflict of interest, please state "The authors declare no conflict of interest." Any role of the funding sponsors in the choice of research project; design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section.

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