ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Research article

Improving Drying Efficiency for Red Chili Peppers Using Ventilated Solar Technology

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Citation:
Srirugsa, T., Kaewpoung, S., Su-hren, W., Panwanitdumrong, K., Chuchit, T., Improving drying efficiency for red chili peppers using ventilated solar technology. *ASEAN J. Sci. Tech. Report.* **2026**, *29*(4), e261032. https://doi.org/10.55164/ajstr.v29i4.261032

Article history:
Received: August 28, 2025
Revised: January 30, 2026
Accepted: February 7, 2026
Available online: March 24, 2026

Abstract: This study compares three drying methods for Jinda red chili peppers: open sun drying (OSD), conventional solar drying (SD), and ventilated solar drying (VSD). Fresh chilies with an initial moisture content of 80% were dried to achieve the industry standard of ≤13.5% final moisture content. Temperature monitoring showed that SD reached the highest peak temperature (75°C), followed by VSD (56°C) and OSD (52°C). Significant differences in drying time were observed: VSD reached appropriate moisture levels in under 17 hours, SD in 34 hours, and OSD in 45 hours. Compared with the first day of SD and OSD, which had drying rates of 49.5% and 55.5%, respectively, VSD showed the highest drying rate, reducing the moisture content to 34.6%. By the second day, VSD had a moisture content of 12.5%, while SD and OSD retained 33.7% and 37.3%, respectively. The enhanced efficiency of VSD is attributed to the combined effects of elevated temperature and mechanical ventilation, which accelerated moisture removal despite the lower chamber temperature than in SD. While solar dryers require greater initial investment than traditional methods, they offer significant advantages in processing time, product quality, contamination prevention, and labor requirements, potentially yielding faster returns on investment. These findings suggest that VSD is optimal for commercial chili drying operations in Thailand's agricultural sector.

Keywords: Red chili peppers; sun drying; solar drying; drying rate

1. Introduction

Red chili peppers (Capsicum annuum L.) originated in Central and South America and have been used in culinary traditions for over 7,000 years. Their global dissemination, driven by European maritime trade networks in the sixteenth century, led to their introduction into Southeast Asia, including Thailand, during the Ayutthaya period, especially from the sixteenth century onward [1], [2]. This adoption significantly transformed Thai cuisine, establishing spiciness as a hallmark of its flavor profile and fostering widespread cultural and culinary integration. Today, chili peppers are a critical economic crop in Thailand, with annual production surpassing 200,000 metric tons, highlighting their agricultural and commercial significance. Domestic consumption accounts for the bulk of Thailand's red chili pepper utilization, with the surplus processed for export markets as dried chilies. There are 3 main uses of Red chili peppers: 1) Use as food. Most Thai food has chili as an ingredient, whether fresh, dried, or ground. 2) Use in the food industry, such as chili paste, curry paste, chili sauce, and canned fish. 3) Medical use because chili contains Capsaicin, which is spicy and can be used as an ingredient in various oral and topical medicines, treating various pains such as colic, back pain, gout, paralysis, and rashes. Thailand's chili pepper industry is dominated by two main varieties: the highly pungent bird's eye chili (Capsicum frutescens L.) and the moderately spicy Jinda chili (Capsicum annuum L.), both widely cultivated in the Northeast, North, East, and Central regions. These red chili peppers are particularly favored in Thai markets for their vibrant color, which enhances their visual appeal in both fresh and dried forms. When dried, Jinda red chilies retain a crisp texture, easy grindability, and high seed content, making them ideal for culinary and industrial applications. Their dense structure, mild aroma, and rich pigmentation further enhance their commercial value, as they can be easily incorporated into various dishes without overpowering other flavors. These superior physicochemical properties explain why these cultivars remain staples in Thai cuisine and key agricultural exports. Thailand's chili pepper export market predominantly comprises dried products, accounting for approximately 50% of total exports with an annual value exceeding 4 billion THB (approximately 123 million USD). This variety's dominance in international markets stems from its reliable processing performance and alignment with global culinary standards for spice ingredients. The substantial export volume of dried Jinda red chili underscores Thailand's competitive advantage in value-added agricultural products within the global spice trade. Due to favorable climatic conditions and consistent sunlight exposure, Thailand predominantly relies on sun-drying for chili processing. However, this traditional method presents multiple challenges that compromise product quality. The open-air drying process requires human labor while remaining susceptible to environmental contaminants, including dust, rainfall, and animal intrusion. These uncontrolled conditions frequently lead to undesirable outcomes such as microbial contamination, inconsistent color, and reduced quality [3]. Solar drying technology has been increasingly adopted for chili processing in Thailand to overcome these limitations. This method produces higher-quality dried chilies than traditional sun-drying. For Jinda red chilies, the process successfully reduces moisture content from approximately 80% in fresh chilies to no more than 13.5% in the final dried product. The controlled conditions of solar drying help maintain product quality while addressing the challenges associated with conventional drying methods. Comparative studies have demonstrated significant differences in processing duration, with sun drying requiring approximately 40 hours versus 24 hours for oven drying to achieve optimal moisture reduction [4]. During nighttime or periods of insufficient sunlight, supplementary measures such as UV irradiation or auxiliary heating systems may be required to prevent mold growth in Jinda chili. However, these introduce additional capital and maintenance costs. A critical consideration in implementing such drying technologies is the production cost, as evidenced by the Khon Kaen Agricultural Engineering Research Center [5], which demonstrated that conventional drying cabinets require approximately 2 years to recover costs [6].

This study therefore focuses on comparing traditional sun drying with solar drying. These systems are selected due to their low initial investment requirements and operational simplicity for household and SME applications.

2. Materials and Methods

2.1 Jinda red chili peppers

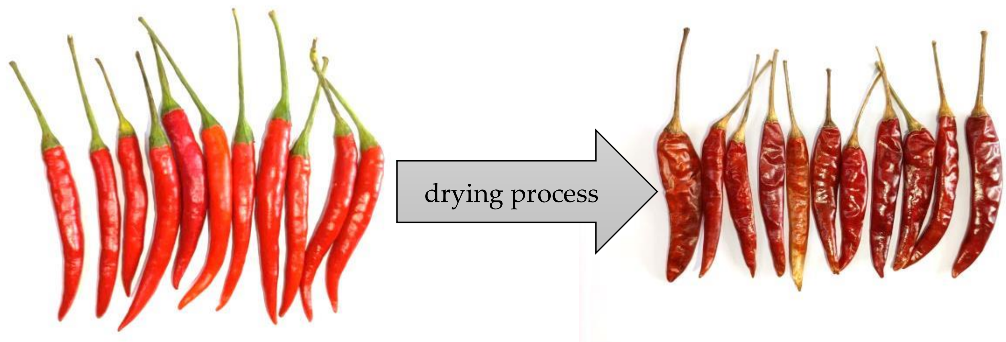

Figure 1. Jinda red chili peppers.

Jinda red chili peppers (Figure 1) were obtained from local markets for 55 THB/kg (approximately 1.7 USD/kg, based on a 32.5 THB/USD exchange rate). The initial moisture content was determined according to AOAC International standard methods [7]. Five replicate samples (200 g each) were dried in an oven maintained at 110 ± 2°C until constant weight was achieved (no further weight change was observed between consecutive measurements). The mean moisture content of fresh Jinda red chili peppers was 80.2% (wet basis). The wet basis moisture content (M_{wb}) can be calculated using equation 1 [4], [8], [9].

$$M_{wb} = \frac{M_w - M_d}{M_w} \times 100 \quad (1)$$

Where,

M_{wb} = the grain moisture content (wet basis)
M_w = the mass of the wet sample (g)
M_d = the mass of dry sample (g)

2.2 Solar dryer

The solar dryers employed in this study were classified into two distinct configurations based on their ventilation mechanisms: 1) a passive natural ventilation design and 2) an active forced ventilation system incorporating an electric fan. Both dryer types featured identical black-painted steel frames with dimensions of 800 mm (width) × 600 mm (length) × 600 mm (height) (shown in figure 2.1). The enclosures were fully insulated with polyurethane sheathing on all six surfaces. Airflow was facilitated through strategically positioned intake vents at the base of the drying chamber, with moist air being expelled through a rear exhaust port. In the forced-ventilation variant, an 8-inch, 10-blade axial fan (12V DC, 80W) was integrated to enhance convective heat transfer. Operational control was automated using a timer relay, maintaining consistent drying conditions daily from 07:00 to 18:00 to align with solar irradiation periods.

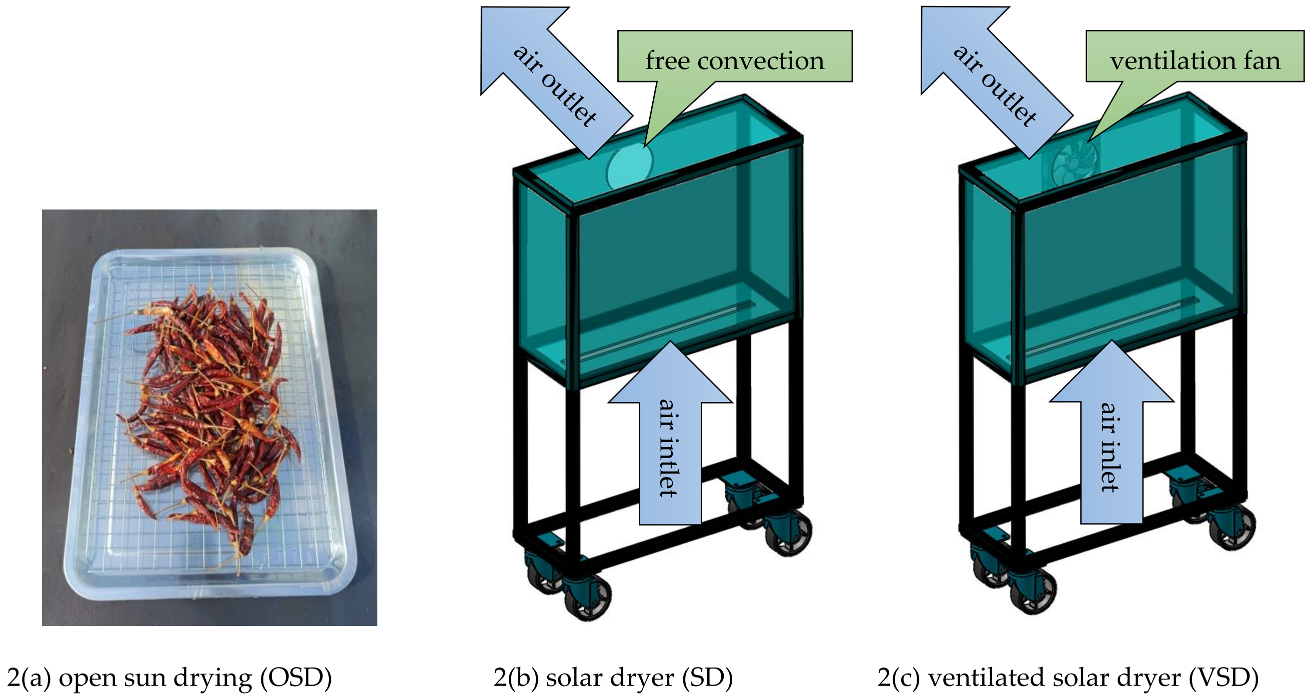

Figure 2. Three drying methods for Jinda red chili peppers.

2.3 Experiment

The study evaluated three drying methods: open-sun drying (OSD), a conventional solar dryer (SD), and a ventilated solar dryer (VSD). For each condition, 200 g of red chili peppers were placed on five mesh grids. Type K thermocouples (±1.5°C) were installed on the OSD sample surface and inside the SD/VSD chambers, with data recorded every 5 minutes using a data logger. Sample weight was measured hourly using an electronic balance (E-Scale KD-KC-1000, 1000 g capacity, ±0.1 g accuracy) until reaching approximately 13.5% (wet basis) moisture content. The experiment was repeated five times for each method. The wet basis moisture content (M_{wb}) can be calculated using equation 1.

2.4 Drying rate (D_R)

The drying rate (D_R) of water from Jinda res chili peppers is defined as the ratio of the weight loss of the material at a particular time interval to the difference in the time period. The drying rate (DR) of the sample was determined using equation 2 [10].

$$D_R = \frac{\Delta M}{\Delta t \times W_2} \quad (2)$$

Where,

D_R = drying rate (g water/g dry matter/h)
$\triangle M$ = weight loss at any time (g)
$\triangle t$ = time difference (hour)
W_2 = weight of sample after drying (g)

2.5 Drying efficiency (η)

System drying efficiency is defined as the ratio of the energy required for moisture evaporation to the heat supplied to the dryer. For solar collectors, this refers to incident solar radiation; for forced-convection dryers, the energy consumed by the fan or blower must also be included in the VSD condition [10], [11].

$$\eta = \frac{Q_{THD}}{Q_{SA} + Q_{EF}} \times 100 \quad (3)$$

Where,

Q_{THD} = total quantity of heat utilized for drying (J)
= $[M \times C_P \times (T_d - T_a)] + [M_W \times \lambda]$
Q_{SA} = heat from solar energy (J)
= $A \times I \times t$
Q_{EF} = electric fan energy (J)
= $W \times s$
M = mass of the product (kg)
C_P = specific heat of wet product (kJ/kg °K)
T_d = temperature of the drying air (°K)
T_a = temperature of the inlet/ambient air (°K)
W_W = mass of water to be removed during drying (kg)
λ = latent heat of vaporization of water (kJ/kg)
η = efficiency of the drying system
A = collector area (m^2)
I = solar insolation (W/m^2)
T = time for which dryer is exposed to solar radiation (s)
W = watt of ventilation system (W)
s = second (s)

3. Results and Discussion

3.1 Temperature profiles across different drying methods

The temperature profiles for the three drying methods—open sun drying (OSD), conventional solar drying (SD), and ventilated solar drying (VSD)—exhibited distinct patterns throughout the daily drying cycle, as shown in Table 1. In all three conditions, temperatures began rising at approximately 8:00, reaching their respective peaks at 13:00, and subsequently declining toward the initial values by 18:00. The SD method consistently demonstrated the highest temperature readings, reaching a maximum of 75°C at 13:00. This elevated temperature can be attributed to the greenhouse effect created within the enclosed drying chamber, where solar radiation is trapped. Heat accumulation occurs due to limited air exchange [4]. The VSD method achieved a moderate peak temperature of 56°C, while OSD recorded the lowest maximum temperature at 52°C. Interestingly, although it had lower peak temperatures than SD, the VSD method demonstrated superior drying efficiency. This phenomenon aligns with findings from [4], who noted that effective moisture removal is influenced by temperature and air circulation rates. Integrating a fan in the VSD setup facilitated continuous moisture evacuation from the drying chamber, preventing humidity saturation that would otherwise impede evaporation. The temperature differential between the drying methods directly impacts the moisture migration rate from the product interior to the surface. Previous research has shown that, in many applications, the temperature inside a solar drying chamber is typically 20-25°C higher than the ambient temperature [12]. Our findings showed a narrower gap of approximately 23°C between the SD and OSD methods at peak conditions, within the expected range for subtropical climates. The optimal drying temperature range for red chili peppers is generally 45-60°C [6]. Temperatures below this range prolong drying time, potentially allowing microbial growth, while temperatures above 60°C may cause case hardening and undesirable color changes. The SD and VSD methods maintained temperatures within or above this optimal range for 5-7 hours daily, whereas the OSD method only briefly reached the lower threshold of this range during peak sunlight hours (shown in Table 1 and Figure 3).

Table 1. Temperature Comparison Across Drying Methods

Time (hr)	Open Sun Drying (OSD) Temperature (°C)	Solar Drying (SD) Temperature (°C)	Ventilated Solar Drying (VSD) Temperature (°C)
7:00	25	25	25
8:00	32	35	33
9:00	35	45	40
10:00	38	53	45
11:00	42	62	48
12:00	45	70	51
13:00	**52**	**75**	**56**
14:00	49	72	52
15:00	46	65	49
16:00	45	56	45
17:00	39	45	40
18:00	35	38	37

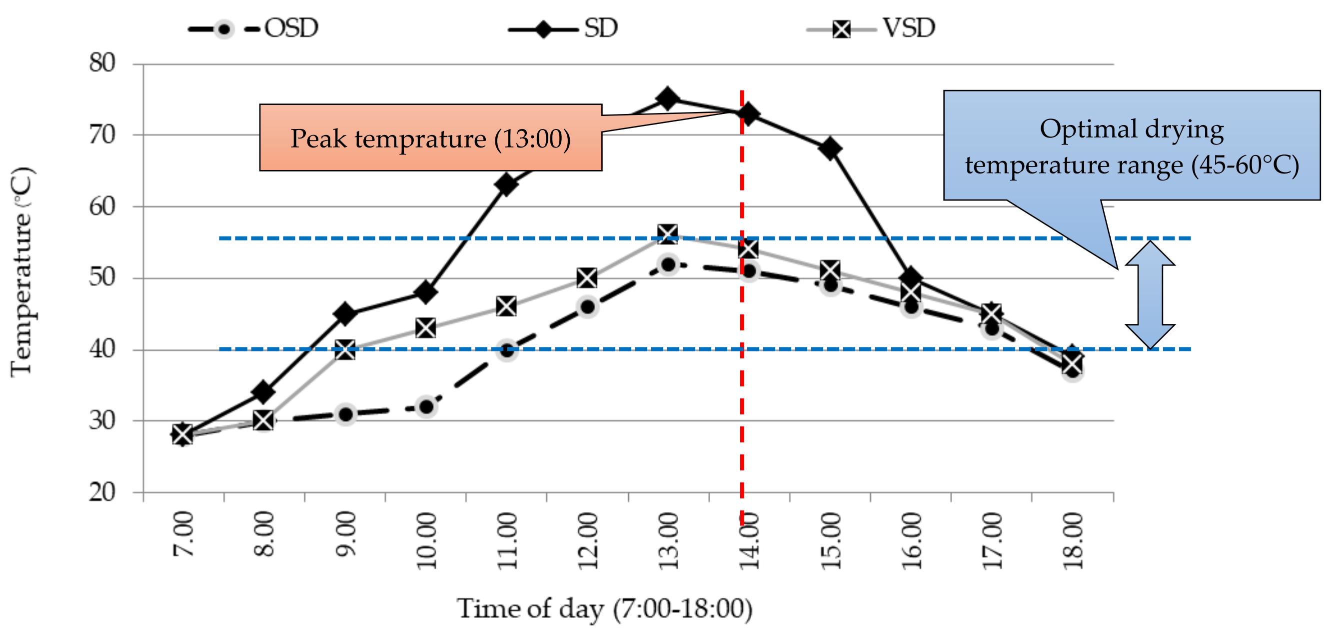

Figure 3. Comparison of temperature profiles for Open Sun Drying (OSD), Solar Drying (SD), and Ventilated Solar Drying (VSD) methods over a 12-hour drying period.

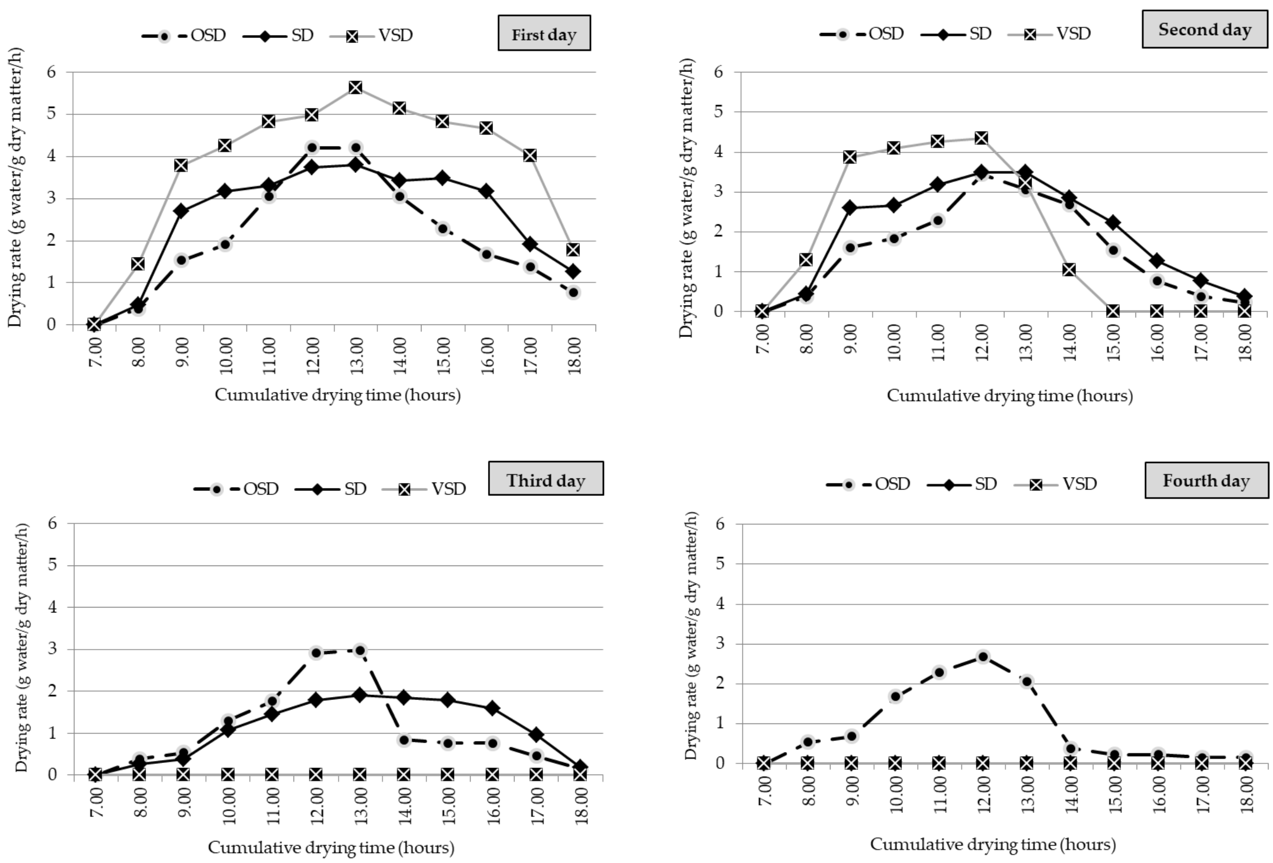

Figure 4. Drying rates for Open Sun Drying (OSD), Solar Drying (SD), and Ventilated Solar Drying (VSD) methods.

3.2 Drying rates and moisture reduction patterns

Analysis of drying kinetics across the three methods revealed significant differences in moisture reduction rates, as illustrated in Figure 4. The ventilated solar drying (VSD) method consistently outperformed, achieving the industry-standard moisture content of <13.5% in just 17 hours. This was followed by conventional solar drying (SD) at 34 hours and open sun drying (OSD) at 45 hours. During the initial drying phase (0-6 hours), all three methods exhibited their highest drying rates, with VSD at 5.6 g water/g dry matter/h, SD at 3.8 g water/g dry matter/h, and OSD at 4.2 g water/g dry matter/h. The initial drying process is characterized by a rapid, constant-rate evaporation phase, followed by a decreasing, falling-rate evaporation phase [13]. The higher initial drying rate in VSD can be attributed to the combined effect of elevated temperature and forced convection, which enhances mass transfer coefficients at the product surface. As drying progressed (6-20 hours), all methods exhibited a characteristic decline in drying rates, entering the falling-rate period [8]. However, VSD maintained significantly higher rates throughout this period, with values approximately 1.5-2 times those of SD and 3-4 times those of OSD. Ventilation drying systems sustain a higher drying rate during the falling-rate period by continuously removing humidified air from the drying chamber. [4]. The moisture content reduction followed an expected exponential decay pattern across all methods. After the first day (12 hours of active drying), VSD reduced the moisture content from 80% to 34.6%, while SD and OSD achieved reductions to 49.5% and 55.5%, respectively (shown in Table 2). This differential performance became more pronounced on the second day, with VSD reaching the target moisture content by hour 17, while SD required an additional 17 hours and OSD needed 28 more hours beyond that point. The superior performance of VSD, despite its lower peak temperature compared to SD (as discussed in Section 3.1), aligns with the findings of Selvaraja et al. [14], suggesting that effective moisture removal in agricultural products depends more on the combination of moderate heat and adequate ventilation than on temperature alone. The fan in the VSD system created a pressure differential that facilitated vapor-pressure-driven moisture migration from the interior of the chili peppers to the surface and, subsequently, to the surrounding air. Interestingly, during the final stages of drying (moisture content <20%), the OSD method demonstrated a slight increase in drying rate (hours 40-45). This phenomenon, also observed by [15], may be attributed to the direct exposure of the product to solar radiation, which becomes more impactful when the moisture content is low and internal resistance to moisture migration is the limiting factor.

Table 2. Daily Moisture Content Reduction Across Drying Methods

Day	Time	Moisture Content (%)		
		OSD	**SD**	**VSD**
1	7:00	80.0	80.0	80.0
1	13:00	64.7	62.8	55.1
1	18:00	55.5	49.5	34.6
2	7:00	55.5	49.5	34.6
2	13:00	42.9	32.1	13.6
2	18:00	37.3	33.7	12.5 [Complete]
3	7:00	37.3	26.2	[Complete]
3	13:00	27.4	19.3	[Complete]
3	18:00	24.5	13.0 [Complete]	[Complete]
4	7:00	24.5	[Complete]	[Complete]
4	13:00	14.5	[Complete]	[Complete]
4	18:00	13.4 [Complete]	[Complete]	[Complete]

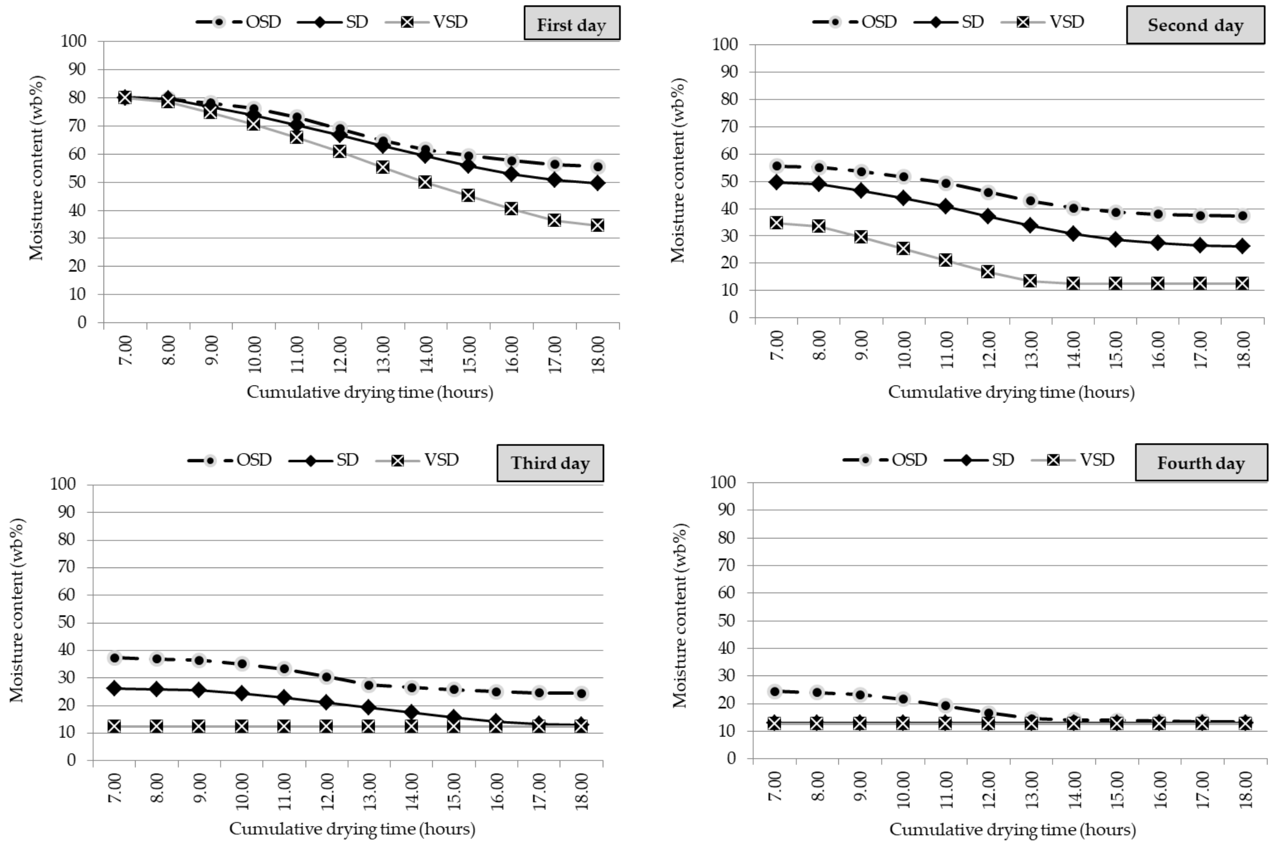

Figure 5. Moisture content reduction for Open Sun Drying (OSD), Solar Drying (SD), and Ventilated Solar Drying (VSD) methods

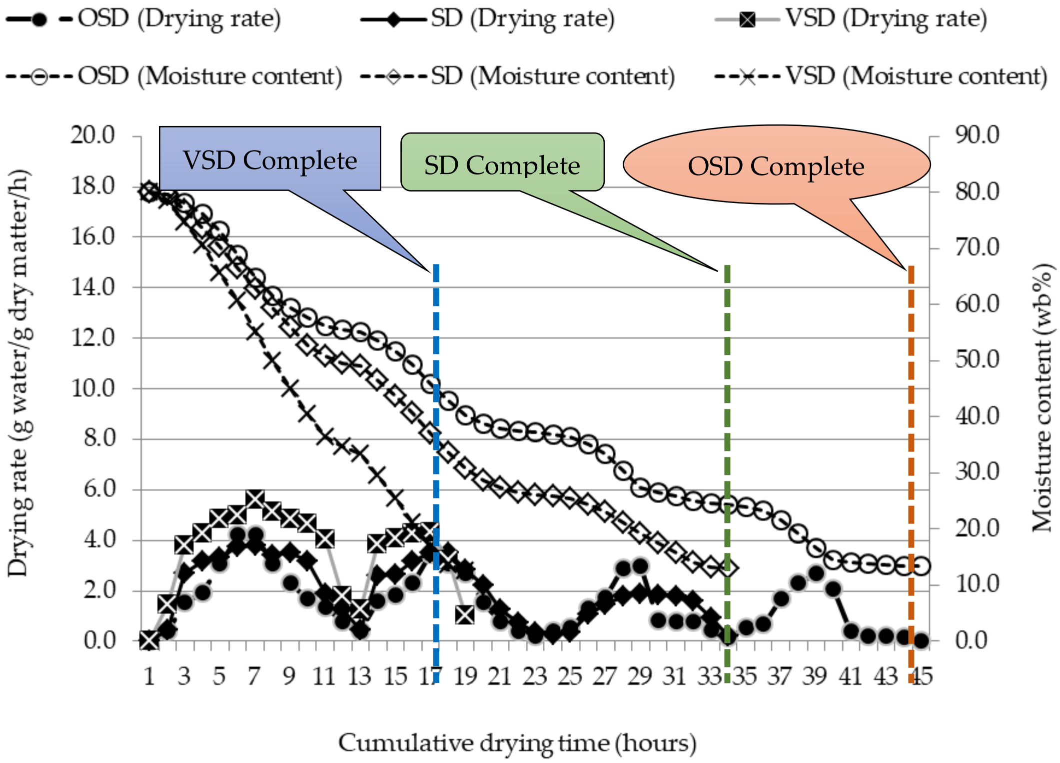

Figure 6. Drying rate and moisture content comparison across methods

3.3 Comparison of drying duration (45 hours for OSD, 34 hours for SD, 17 hours for VSD)

The total drying duration required to reach the industry-standard moisture content of <13.5% varied significantly across the three methods, as illustrated in Figure 3. Ventilated solar drying (VSD) demonstrated superior efficiency, requiring only 17 hours of active drying spread across two days. The conventional solar drying (SD) method required 34 hours (three days), while open-sun drying (OSD) required 45 hours (four days) to achieve comparable results. The reduced drying time for VSD represents a 50% improvement over SD and a 62% improvement over OSD. This substantial time reduction aligns with findings from [8], who reported 30-50% time savings when comparing ventilated solar drying systems to conventional methods for Capsicum annuum. The efficiency advantage of VSD (41.6%) over SD (22.7%) and OSD (17.0%) further demonstrates the effectiveness of forced convection in accelerating drying. The combination of moderate heating and forced air circulation creates an optimal environment for dehumidification by sustaining a favorable vapor pressure gradient between the product and the surrounding air [16]. This principle explains VSD's superior performance despite its lower peak temperature than SD. While SD reached higher temperatures (75°C vs. 56°C), the absence of forced air circulation resulted in localized humidity saturation, creating a barrier to further moisture removal. The practical implications of these duration differences are significant for commercial operations. Reducing the drying time directly enhances productivity, minimizes labor costs, and mitigates the risk of product spoilage [17]. Based on the estimated labor hours required for each method (16, 12, and 8 hours for OSD, SD, and VSD, respectively), VSD offers substantial operational advantages despite the additional energy consumption for fan operation (80 Wh). The economic impact of these efficiency differences is particularly relevant for Thailand's chili processing industry, which handles approximately 200,000 metric tons annually [18], [19]. Khon Kaen Agricultural Engineering Research Center [5] estimated that upgrading from traditional drying methods to more efficient technologies could reduce processing costs by 25-30% while improving product quality and consistency. Our findings suggest that implementing VSD systems would yield returns on investment within approximately two harvesting seasons for medium-scale operations, primarily through labor savings and increased processing capacity. Interestingly, the relationship between drying method sophistication and efficiency appears nearly linear (Figure 3), suggesting that incremental improvements to the drying system produce proportional benefits in processing time. This trend corresponds with observations from [6], who noted that technological enhancements in agricultural processing systems typically yield diminishing returns after reaching certain efficiency thresholds.

Table 3. Performance Comparison of Different Drying Methods for Red Chili Peppers

Parameter	OSD	SD	VSD
Total drying time (hours)	45	34	17
Days required	4	3	2
Peak temperature (°C)	52	75	56
Average drying rate (g water/g dry matter/h)	1.5	2.0	3.7
Energy consumption (fan) (Wh)	0	0	80
Estimated labor hours	16	12	8
Final moisture content (%)	13.4	13.0	12.5

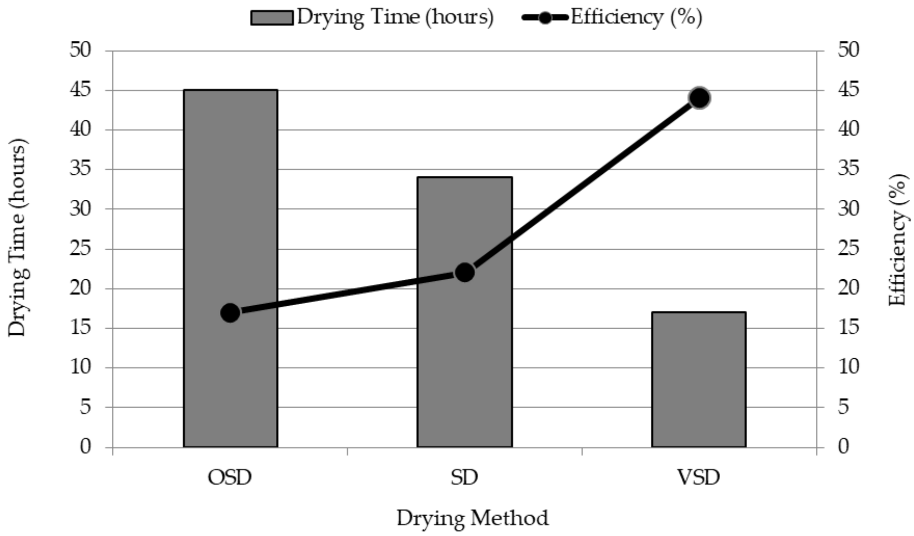

Figure 7. Comparative drying time and efficiency

4. Economic and Practical Implications

The initial capital investment required for each drying method varies considerably, with important implications for adoption by small-scale farmers and processors. As shown in Table 4, open sun drying (OSD) requires minimal equipment investment (approximately 500 THB or 15.4 USD), consisting primarily of drying mats and basic handling tools. Although sun drying has a lower initial cost, it entails significant disadvantages, notably extensive space requirements and the risk of weather dependence and product contamination. These drawbacks can lead to hidden costs, such as increased labor expenses or product loss [15]. The conventional solar dryer (SD) requires a moderate investment of approximately 5,500 THB (169.3 USD), primarily for construction materials, including the frame structure, transparent covering, and insulation. According to the Khon Kaen Agricultural Engineering Research Center [5], such systems can be constructed using locally available materials, reducing costs while significantly improving upon traditional methods. The design simplicity allows for local fabrication and maintenance, an essential consideration for rural implementation [4]. The ventilated solar dryer (VSD) has the highest initial investment at approximately 8,500 THB (261.6 USD), with additional costs for the fan, controller components, and electrical integration. Despite representing a 42% higher investment than conventional solar dryers, the components contribute significantly to increased efficiency and reliability [14]. Modular design enables manufacturers to begin with a basic solar drying system. To achieve higher efficiency, the system's ventilation must be enhanced, often by adding appropriately sized ventilation fans to the drying chamber [6].

Labor requirements account for a significant portion of operational costs in agricultural processing, particularly for labor-intensive crops such as chili peppers. For a standard 10 kg batch of fresh red chili peppers, our analysis indicated labor requirements of 23, 17, and 9 hours for OSD, SD, and VSD methods, respectively. These differences translate directly to operational costs, with labor expenses of 1,044 THB (32.2 USD), 696 THB (21.4 USD), and 348 THB (10.7 USD) per batch based on current agricultural wages in Thailand. Beyond direct labor costs, several operational efficiency factors favor advanced drying systems. Specifically, the VSD method demonstrated the lowest spoilage rate at 3%, compared to 5% for SD and 12% for OSD, representing significant product conservation [17]. The reduction in product spoilage in a controlled drying environment is attributed to consistent moisture removal and minimal exposure to environmental contaminants [12]. The processing capacity also varied substantially, with monthly throughput potential of 70 kg, 100 kg, and 150 kg for OSD, SD, and VSD, respectively. This increased production capacity enables processors to manage seasonal harvest volumes more efficiently, thereby reducing post-harvest losses that often occur when existing capacity limits are exceeded [18]. Furthermore, improvements in product quality consistency associated with controlled drying conditions often command premium pricing in domestic and export markets [16].

Despite higher initial investments in solar drying technologies, their economic advantages become evident through return-on-investment analysis. Based on operational savings relative to traditional methods, the payback periods for SD and VSD systems were calculated at 4.5 and 2.5 months, respectively, assuming consistent production volumes. These remarkably short payback periods align with observations from [13], who reported rapid investment recovery for solar drying technologies applied to high-value agricultural products. The annual return on investment percentages of 46.6% for SD and 74.6% for VSD underscore the exceptional economic efficiency of these technologies. These returns primarily derive from reduced labor costs, increased processing capacity, and improved product quality. Cooperative operations could further reduce individual investment burdens while simultaneously maintaining access to improved processing capacity [15]. Beyond direct financial returns, several long-term economic benefits favor advanced drying systems that are not captured in traditional ROI calculations, notably reduced dependency on favorable weather, enhanced production scheduling, and improved market access via consistent product quality [20]. These factors contribute to business resilience and sustainability, essential considerations in Thailand's increasingly variable climate conditions.

Table 4. Economic Comparison of Red Chili Pepper Drying Methods

Parameter	OSD	SD	VSD
Initial Investment			
Equipment cost (THB)	500	5,500	8,500
Set up labor (hours)	4	8	10
Estimated useful life (years)	1	5	5
Operational Costs			
Labor hours per 10 kg batch	23	17	9
Labor cost per batch (THB)	1,044	696	348
Energy cost per batch (THB/month)	0	0	5
Spoilage rate (%)	12	5	3
Production Capacity			
Batches per month	7	10	15
Processing capacity (kg/month)	70	100	150
Product quality consistency	Low	Medium	High
Financial Analysis			
Monthly operational savings vs. OSD (THB)	-	1,260	3,360
Payback period (months)	-	4.5	2.5
Annual return on investment (%)	-	46.6	74.6

4. Conclusions

This study evaluated the performance of three drying methods for Jinda red chili peppers: open sun drying (OSD), conventional solar drying (SD), and ventilated solar drying (VSD). The findings revealed substantial differences in efficiency, with drying durations of 45, 34, and 17 hours for OSD, SD, and VSD, respectively, all achieving the industry-standard final moisture content below 13.5%. The superior performance of VSD can be attributed to the synergistic effect of elevated temperature and forced air circulation, which maintained optimal drying conditions throughout the process. While SD achieved higher peak temperatures (75°C versus 56°C for VSD), the absence of mechanical ventilation led to humidity saturation in the drying chamber, limiting moisture removal rates. Conversely, the fan in the VSD system continuously evacuated moisture-laden air, sustaining favorable vapor pressure gradients despite lower operating temperatures. Temperature profiles and drying rates demonstrated distinct patterns across all methods, with the highest drying rates occurring during the initial 6-8 hours, followed by a characteristic falling-rate period. The VSD method maintained significantly higher drying rates throughout all phases, achieving complete drying in 2 days compared to 3 and 4 days for SD and OSD, respectively. Economic analysis revealed compelling advantages of advanced drying technologies despite higher initial investment costs. The VSD system offered substantial labor savings, reduced processing time, lower spoilage rates, and increased throughput capacity, which resulted in a remarkably short payback period of less than one month under typical production conditions. These economic benefits make VSD particularly appealing for small-scale producers and SMEs seeking to improve production efficiency and product quality. Beyond economic considerations, the controlled environment of solar drying systems mitigates contamination risks and weather dependencies inherent in traditional methods. For Thailand's chili production sector, widespread adoption of improved drying technologies could significantly enhance processing capacity, product quality, and market competitiveness while reducing post-harvest losses. Future research should explore optimizing ventilation parameters, integrating renewable energy sources for fan operation, and scaling up for commercial implementation.

5. Acknowledgements

We are grateful to the Faculty of Engineering, Thaksin University, Phatthalung Campus, for allowing the use of the location for this research experiment.

Author Contributions: The following are the contributions of each author in this research: Conceptualization: Tanawat Srirugsa and Tawat Chuchit; Methodology: Tanawat Srirugsa and Kansinee Panwanitdumrong; Software: Wiwat Su-hren and Supachai Kaewpoung; Writing—review and editing: Tawat Chuchit and Wiwat Su-hren; Project administration: Tanawat Srirugsa.

Funding: This research received no external funding.

Conflicts of Interest: The authors of this study hereby state that they have no conflicts of interest.

References

[1] Anderson, H. A. *Chillies: A Global History*; Reaktion Books: London, 2016.

[2] Andrews, J. *The Pepper Trail: History & Recipes from around the World*; 1999.

[3] Hasan, M. U.; Malik, A. U.; Ali, S.; Imtiaz, A.; Munir, A.; Amjad, W.; Anwar, R. Modern Drying Techniques in Fruits and Vegetables to Overcome Postharvest Losses: A Review. *J. Food Process. Preserv.* **2019**, *43* (12), e14280. https://doi.org/10.1111/jfpp.14280

[4] Wongbubpa, N.; Treeamnuk, K.; Treeamnuk, T. Influence of Drying Air Velocity Characteristics on Paddy Drying. *RMUTP Res. J.* **2022**, *16*, 165–176.

[5] Research Center. *Research and Development of Technology and Machines for Chili*; Department of Agriculture, Ministry of Agriculture and Cooperatives: Khon Kaen, Thailand, 2009.

[6] Cruz-Domínguez, O.; Carrera-Escobedo, J. L.; Guzman-Valdivia, C. H.; Ortiz-Rivera, A.; García-Ruiz, M.; Duran-Muñoz, H. A.; Vidales-Basurto, C. A.; Castaño, V. M. A Novel Method for Dried Chili Pepper Classification Using Artificial Intelligence. *J. Agric. Food Res.* **2021**, *3*, 100099. https://doi.org/10.1016/j.jafr.2021.100099

[7] AOAC International. *Official Methods of Analysis of AOAC International*, 17th ed.; AOAC International: Gaithersburg, MD, 2000.

[8] Fudholi, A.; Othman, M. Y.; Ruslan, M. H.; Sopian, K. Drying of Malaysian *Capsicum annuum* L. (Red Chili) Dried by Open and Solar Drying. *Int. J. Photoenergy* **2013**, *2013*, 167895. https://doi.org/10.1155/2013/167895

[9] Benyoucef, M.; Panigrahi, S. S. Fluidization-Bed Drying and Microwave Radiation Effects on Drying Rate, Fatty Acid, Protein and Germination of Rapeseed. *J. Food Compos. Anal.* **2025**, *142*, 107562. https://doi.org/10.1016/j.jfca.2025.107562

[10] Jain, R.; Paul, A. S.; Sharma, D.; Panwar, N. L. Enhancement in Thermal Performance of Solar Dryer through Conduction Mode for Drying of Agricultural Produces. *Energy Nexus* **2023**, *9*, 100182. https://doi.org/10.1016/j.nexus.2023.100182

[11] Korbuakaew, K.; Phoosomma, P. The Approach for Boosting the Drying Chamber's Temperature by Pulse Copper Pipes to Conduct Heat. *ASEAN J. Sci. Technol. Rep.* **2025**, *28* (3), e254983. https://doi.org/10.55164/ajstr.v28i3.254983

[12] Meghwar, B. L.; Khan, A.; Lakhiar, I. A.; Mirani, A. A.; Daper, M. S.; Kalroo, M. W. Comparison between Solar Tunnel, Solar-Cum Gas Dryer, and Open Sun Drying Methods for Drying Red Chilies. *Pak. J. Agric. Res.* **2023**, *36*, 63–70. https://doi.org/10.17582/journal.pjar/2022/36.1.63.70

[13] Nimrothama, C.; Songprakorpa, R.; Thepa, S.; Monyakul, V. Experimental Research of Drying Red Chili by Two Methods: Solar Drying and Low-Temperature System Drying. *Energy Procedia* **2017**, *138*, 512–517. https://doi.org/10.1016/j.egypro.2017.10.237

[14] Selvaraja, M.; Sadagopan, P.; Vijayan, S. Investigation of the Thermal Performance of an Indirect Forced Convection Solar Dryer for Tapioca Chips Drying. *Desalin. Water Treat.* **2021**, *230*, 430–441. https://doi.org/10.5004/dwt.2021.27214

[15] Jeentada, W.; Niyomvas, B.; Thailul, A. Experimental Study on Drying Conditions of Solar Fish Dryer with Temperature Controlled by Open–Closed Ventilation System. *J. KMITNB* **2018**, *28*, 525–536.

[16] Dussan, E. D.; Uribe, J. R.; Banout, J. Design and Evaluation of a Hybrid Solar Dryer for Postharvesting Processing of Parchment Coffee. *Renew. Energy* **2023**, *215*, 118961. https://doi.org/10.1016/j.renene.2023.118961

[17] Krabch, H.; Tadili, R.; Idrissi, A. Design, Realization and Comparison of Three Passive Solar Dryers: Orange Drying Application for the Rabat Site (Morocco). *Results Eng.* **2022**, *15*, 100532. https://doi.org/10.1016/j.rineng.2022.100532

[18] Purika, S.; Aunaudomvana, N.; Panyoyai, N. Pretreatment Techniques of Dehydrated Red Spur Chilli Peppers for Compliant Thai Agricultural and Community Food Standards. *Sci. Technol. Community* **2023**, *1*, 1–18.

[19] Lakshmi, D. V. N.; Palanisamy, M. Design and Development of Mixed Mode Forced Convection Solar Dryer for Drying of *Curcuma zedoaria*. In *Proc. Int. Conf. Therm. Eng. (ICTEA)*; **2019**.

[20] Nukulwar, M. R.; Tungikar, V. B. A Review on Performance Evaluation of Solar Dryer and Its Material for Drying Agricultural Products. *Mater. Today: Proc.* **2021**, *46*, 345–349. https://doi.org/10.1016/j.matpr.2020.08.354