Vol. 14, No. 6 (2025): 2239 - 2249
http://dx.doi.org/10.23960/jtepl.v14i6.2239-2249

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Investigation of Drying Time and Final Moisture Content of Arabica beans in a Solar Drying Chamber

Rendi Ramdhani[1], Selly Septianissa[1,✉], Ahmad Rajani[2]

[1] Department of Mechanical Engineering, Widyatama University, Bandung, INDONESIA.

[2] Research Centre for Energy Conversion and Conservation, INDONESIA.

Article History:

Received : 22 May, 2025
Revised : 09 June, 2025
Accepted : 29 July, 2025

Keywords:

Air velocity,
Arabica beans,
Drying rate,
Moisture content,
Phase change material,
Solar drying chamber.

Corresponding Author:
✉ selly.septianissa@widyatama.ac.id
(Selly Septianissa)

ABSTRACT

Drying is a critical stage that affect directly the quality, storability, and market value of Arabica coffee beans. The objective of this study was to investigate the performance of a solar drying chamber integrated with a thermal collector and phase change material (PCM), operated under a constant airflow velocity of 9.2 m/s. Arabica beans of 1500 g were dried over two observation days, with chamber temperatures ranging from 40 °C to 46.5 °C and peak solar radiation of 1122 W/m². The results showed that the system effectively maintained thermal stability and drying performance despite fluctuations in solar input. The analysis revealed at Day 2 achieved a higher and faster moisture reduction due to improved solar conditions and absorber efficiency, with drying rates peaking at over 42 g vapor per hour in the third hour. In contrast, at Day 1 the drying rate peaked in the third hour at approximately 22.45 g vapor/h. Day 1 exhibited a more stable but slower drying trend. Overall, the system successfully reduced the beans' moisture content to below 12.8% in within under 14 hours, with Tray 2 delivering the most consistent results. These findings demonstrate that the integration of solar thermal energy, PCM, and forced convection application significantly improved drying efficiency and reliability, offering a sustainable alternative for post-harvest processing, especially in regions with variable weather conditions.

1. INTRODUCTION

Production represents a vital agricultural sector for many tropical countries, not only as a source of export revenue but also as a key livelihood for smallholder farmers (Bacsi *et al*., 2022; Jawo *et al*., 2023; Pancsira, 2022; Siles *et al*., 2022). Among the varieties cultivated, coffee arabica stands out for its superior flavor profile, acidity, and aroma qualities that are highly valued in the global specialty market (Abdelwahab *et al*., 2024; Baqueta *et al*., 2024; Freitas *et al*., 2024). These sensory characteristics, however, are highly sensitive to post harvest handling, particularly the drying phase (Coelho *et al*., 2024). Improper drying can compromise bean integrity, reduce shelf life, and lead to quality degradation that affects cupping scores and market value (Al-Ghamdi *et al*., 2024; Moon *et al*., 2024).

In many producing regions, the drying process continues to rely heavily on open sun exposure, primarily due to its simplicity and low capital requirements (Al-Ghamdi *et al*., 2024; Septianissa & Chandrasari, 2025) While accessible, this method is labor-intensive, slow, and susceptible to unpredictable weather patterns. Furthermore, the prolonged drying time under uncontrolled conditions increases the risk of microbial contamination, uneven moisture distribution, and post-harvest losses (Girma, 2023; Martinius *et al*., 2022; Septianissa & Chandrasari, 2024; Vesković, 2025). These limitations have spurred interest in alternative drying technologies that can deliver consistent and efficient moisture removal while maintaining bean quality (Acar *et al*., 2022; Andrade *et al*., 2024; Soeswanto *et al*., 2021).

Solar assisted drying systems offer a promising intermediate solution between traditional sun drying and high cost mechanical dryers (Duque-Dussán *et al*., 2023; Kamarulzaman *et al*., 2021; Meja *et al*., 2025). By harnessing renewable solar energy and applying basic engineering controls, such systems can create more stable drying environments (Meja *et al*., 2025; Pandey *et al*., 2024). The addition of components such as air collectors and forced convection mechanisms has shown potential in significantly reducing drying time while improving the uniformity of moisture reduction across the bean mass (Soeswanto *et al*., 2021). These systems are especially appealing in rural areas with abundant sunlight and limited electricity infrastructure (Siagian *et al*., 2024a; Izuka *et al*., 2023).

A key factor influencing the efficiency of solar drying systems is air velocity, which governs the rate of heat and mass transfer within the drying chamber (Daş *et al*., 2021). Higher air speeds can enhance moisture removal by reducing the boundary layer resistance on the bean surface, but excessive airflow may also lead to surface hardening and uneven internal drying (Alves *et al*., 2020; Duque-Dussán *et al*., 2023) Optimizing this parameter is therefore crucial to achieving both effective drying rates and desirable final moisture content. However, many existing studies focus on low-to-moderate air velocities, leaving a gap in the literature concerning high-velocity airflow in solar drying contexts (Jha & Tripathy, 2024; Siagian *et al*., 2024a).

This study seeks to investigate the drying behavior of Arabica beans in a solar drying chamber operating at a constant air velocity of 9.2 m/s. The research aims to evaluate how such airflow intensity, coupled with solar thermal input, affects the drying duration and final moisture content of the beans. By analyzing drying performance under these conditions, the results of this study are expected to contribute on valuable insights into the design and operational optimization of solar drying systems for, with implications for improving post-harvest quality and processing efficiency in resource-constrained environments.

2. METHODS

2.1. Materials

Main material used in this study was Arabica coffee beans originated from Pangalengan, West Java. In general, Arabica beans are typically oval shaped with a curved central groove, and have an average length ranging from 8 to 10 mm. The beans were harvested at optimal ripe and had an initial moisture content of 28.5% (wet basis) prior to the drying process. The beans followed standard post-harvest treatment including de-pulping, thorough washing, and 7-h fermentation process aimed at mucilage removal before entering the drying phase. After fermentation, the beans were carefully rinsed and prepared for the drying phase. For drying consistency, the beans were distributed uniformly in a thin layer (approximately 0.5–1 cm thick) on drying trays.

2.2. Equipment

The system was equipped with a Phase Change Material (PCM) unit, which functions as a thermal energy storage component. The PCM absorbs excess heat during periods of high solar radiation and releases it gradually when solar input decreases, thereby maintaining thermal stability inside the drying chamber. This thermal buffering helps ensure a

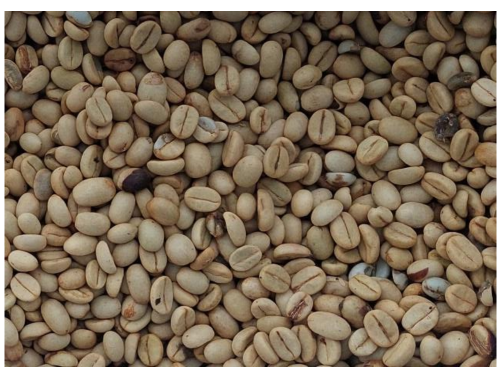

Figure 1. Arabica beans from Pangalengan, West Java

consistent drying environment, reduces temperature fluctuations, and allows the drying process to continue even during cloudy conditions or late afternoon periods when sunlight weakens.

The drying setup featured a mobile solar-powered drying unit, designed to maximize heat transfer and enhance air circulation. The primary component of this system was drying chamber sizing of (900×800×1200) mm fabricated using aluminum sheets completed with glass wool insulation layer to minimize heat loss. The interior was lined with aluminum foil to maintain hygiene and avoid contamination. The drying chamber was equipped with 20 flexible trays that can be easily removed and reinstalled, allowing for adjustable drying capacity and easy cleaning.

A single pane glass solar collector was used, featuring a black-painted metal absorber to optimize solar energy absorption. The collector measured (1000×800) mm and operated by allowing solar radiation to pass through the transparent glass surface, which was then absorbed by the black metal plate. This plate converted the incoming solar radiation into heat energy, which in turn heated the air flowing through the collector. The heated air was directed into the drying chamber and also circulated around the PCM housing. The PCM absorbed excess thermal energy during periods of high solar intensity and gradually released it when solar input decreased, thereby helping to maintain a relatively constant and stable drying temperature within the chamber. This collector supplied heated air directly to the drying chamber. Air circulation system was performed using an axial blower was employed to channel heated air from the collector into the drying chamber, maintaining an airflow velocity of 9.2 m/s. This setup enhanced the efficiency of convective drying and ensured even moisture reduction.

Key environmental parameters including chamber temperature and relative humidity were monitored using thermocouples and sensor connected to a data logger. Solar radiation was tracked with a solar power meter, and the moisture content of the beans was measured periodically using a moisture tester.

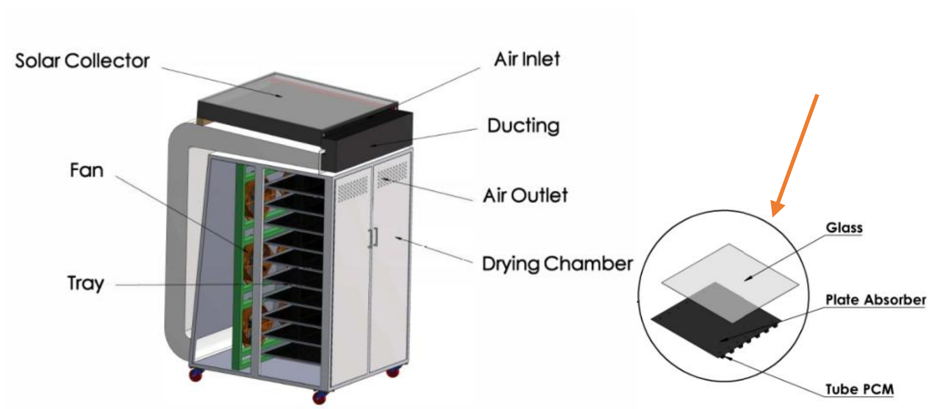

Figure 2. Coffee dryer based on forced convection

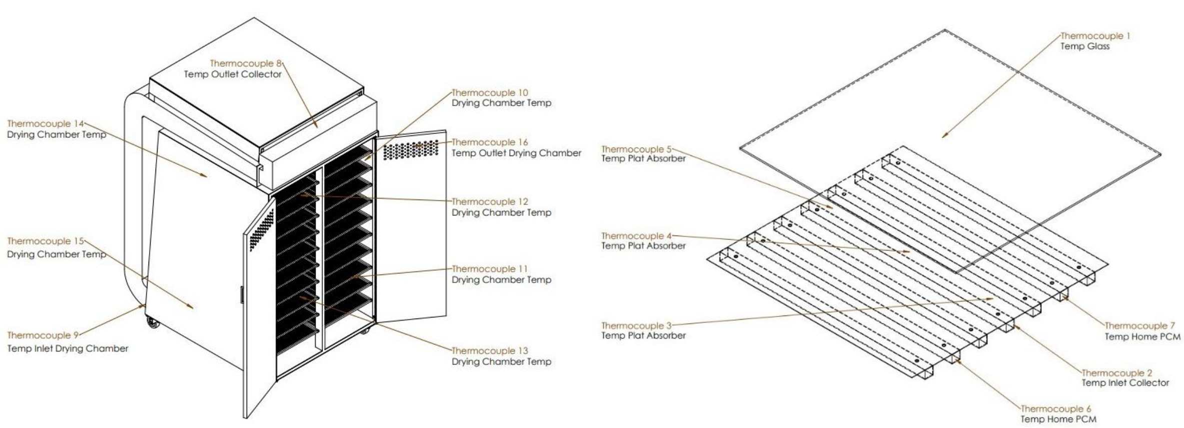

Figure 3. Sensor thermocouple installation in the coffee dryer

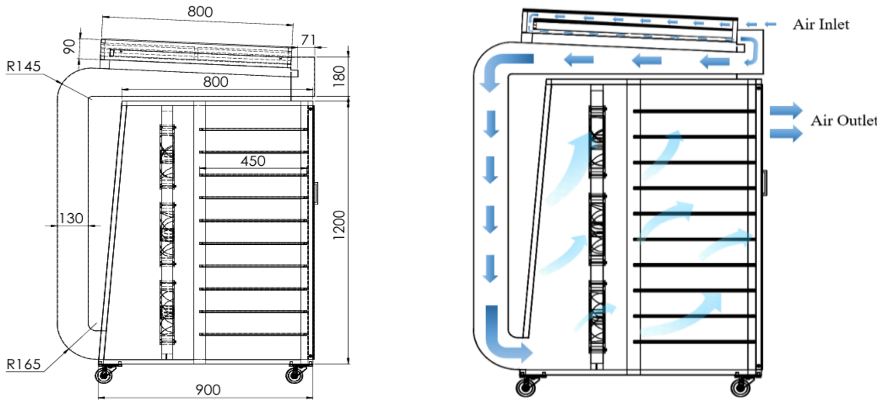

Figure 4. Layout of components in the coffee solar drying system

2.3. Experimental Procedure

The drying system utilized solar energy absorbed by a black metal plate in the collector to heat the air. The heated air was then circulated into the drying chamber by a blower at a speed of 9.2 m/s to evenly evaporate moisture from the beans. The system was also equipped with PCM, which stores and gradually releases heat to maintain a stable temperature despite fluctuations by weather conditions. The drying experiment was conducted over two consecutive days to achieve the target final moisture content.

The drying trials were performed from 08:00 a.m to 03:00 p.m, corresponding with periods of peak solar intensity with temperature at 46.5 ℃ in drying chamber. Each batch trial processed 1500 gram of Arabica beans, which was evenly distributed across 20 trays inside the drying chamber to ensure uniform drying and optimal air exposure. The beans remained in the drying chamber until achieving the target moisture content of approximately 12.8% wet basis, which is considered safe for storage and export. The moisture content was periodically measured using a moisture meter specifically designed for beans.

Environmental and operational parameters, including chamber temperature (°C), relative humidity (%), solar radiation intensity (W/m²), and ambient conditions, were monitored using specific instruments. Thermocouples connected to a data logger were used to measure chamber temperature. Thermos hygrometer was employed to monitor relative humidity. Solar radiation intensity was measured using a solar power meter. All ambient parameters were recorded periodically at 15 min intervals to ensure thermal performance evaluation. The performance of the solar dryer was evaluated based on moisture reduction rate and drying duration.

3. RESULTS AND DISCUSSION

3.1. Thermal Performance of the Solar Drying Chamber

The daily patterns of sun radiation had a significant impact on the thermal performance of solar drying chamber. Over the course of the five observation days, solar radiation followed a bell-shaped curve, with peak intensities taking place between 11:00 am and 12:30 pm, as seen in Figure 5a. Day 1 had the lowest radiation intensity values, while Day 4 had the highest, with 1122 W/m^2. The thermal response of the drying components and, consequently, the drying process efficiency was directly impacted by is these variations. In addition to solar radiation, another critical factor influencing drying performance was the relative humidity (RH) of the air. During the drying period, the RH levels were measured using a a thermohygrometer and were observed to decrease significantly during peak solar hours—from around 70% in the morning to as low as 40% by midday. This reduction in RH enhanced the air's capacity to absorb moisture from the beans, contributing to faster drying rates.

Figure 5b illustrates the temperature distribution within the PCM storage chamber, which serves as a thermal energy buffer by absorbing and releasing latent heat during phase transitions. The use of PCM in solar drying systems has been proven effective in stabilizing temperature and extending drying duration, particularly under fluctuating solar radiation.

Temperatures in the PCM chamber gradually increased during daylight hours and remained relatively stable in the afternoon, particularly from Day 2 to Day 5. Peak PCM temperatures ranged between 60 °C and 72 °C, highlighting the effectiveness of PCM in storing and gradually releasing heat energy. This buffering capacity helps prevent significant temperature drops and extends the chamber's thermal activity beyond peak sunlight hours.

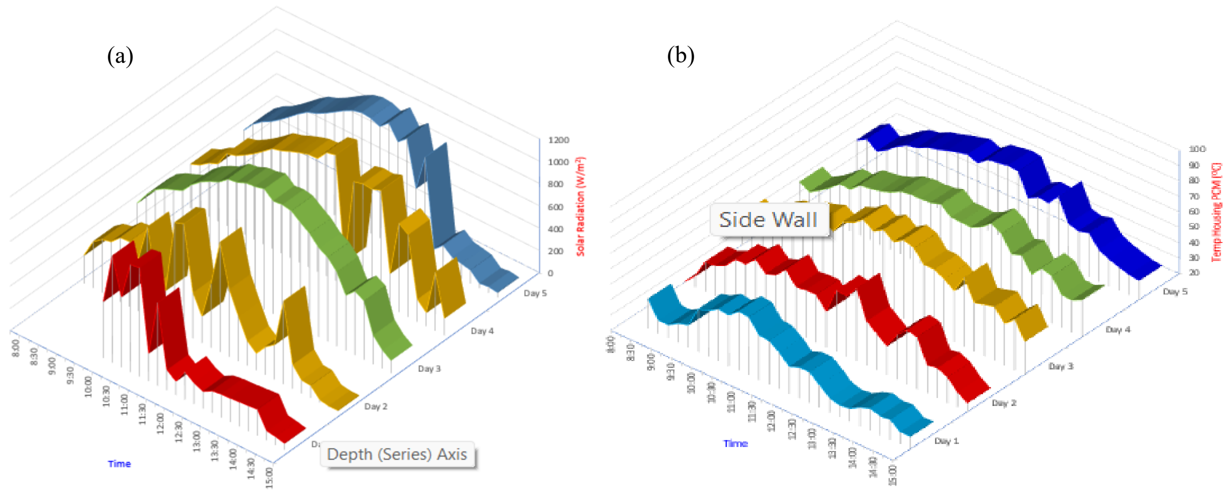

Figure 5. Condition during 5-day field testing for mobile solar dryer: (a) Daily solar radiation, (b) PCM Housing Temperature

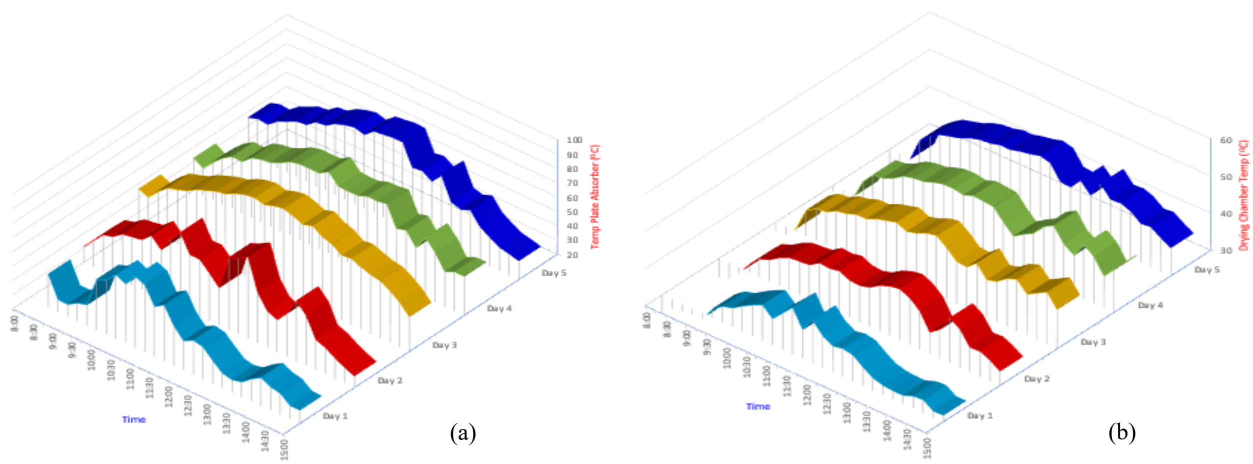

Figure 6. Performance of mobile solar dryer: (a) Aluminum absorber plate temperature, (b) Drying chamber temperature

Similarly, Figure 6a demonstrates the performance of the aluminum absorber plate, which plays a critical role in converting solar radiation into heat. On Day 3, the absorber plate consistently exceeded 72 °C during midday, indicating high absorption efficiency. The substantial temperature difference between the absorber plate and the drying air facilitated efficient heat transfer into the drying chamber. The internal temperatures of the drying chamber, as shown in Figure 6b, ranged from 40 °C to 46.5 °C. This temperature range is considered ideal for drying Arabica coffee beans, promoting rapid moisture reduction while maintaining quality. Notably, from Day 3 to Day 5, the chamber maintained higher and more consistent temperatures than the first two days, corresponding to higher solar radiation and improved performance of the absorber and PCM.

3.2. Drying Behavior and Process Efficiency

The design of the solar collector, PCM integration, and forced air convection at a velocity of 9.2 m/s collectively contributed to efficient and uniform drying across all trays. The high airspeed enhanced heat and mass transfer within the chamber, ensuring consistent exposure of beans to hot air and preventing uneven moisture loss. Among all the trays tested, tray 2 consistently produced beans with a final moisture content of 10%, with a final moisture content of 10%, starting from an initial moisture content of 28.5% wet basis, aligning with green storage standards.

Despite receiving lower solar input on Day 1 and Day 2, the drying system was still able to maintain chamber temperatures above 40 °C, supported by thermal insulation and latent heat release from the PCM. This resilience demonstrates that the system remains operational under moderate environmental conditions, making it suitable for variable tropical climates. The experimental drying duration of 21 hours to achieve a 12.8% moisture content was significantly faster than traditional sun drying methods, which can take several days due to unpredictable weather. This reduction in drying time not only enhances processing efficiency but also minimizes the risk of contamination and quality degradation due to prolonged exposure.

Overall, the results confirm that integrating solar energy with thermal storage and forced convection provides a reliable and energy-efficient solution for post-harvest processing. For future improvements, further research may explore optimizing PCM volume, adjusting airflow direction, or enhancing the collector's surface treatment to boost system performance and potentially enable nighttime drying cycles.

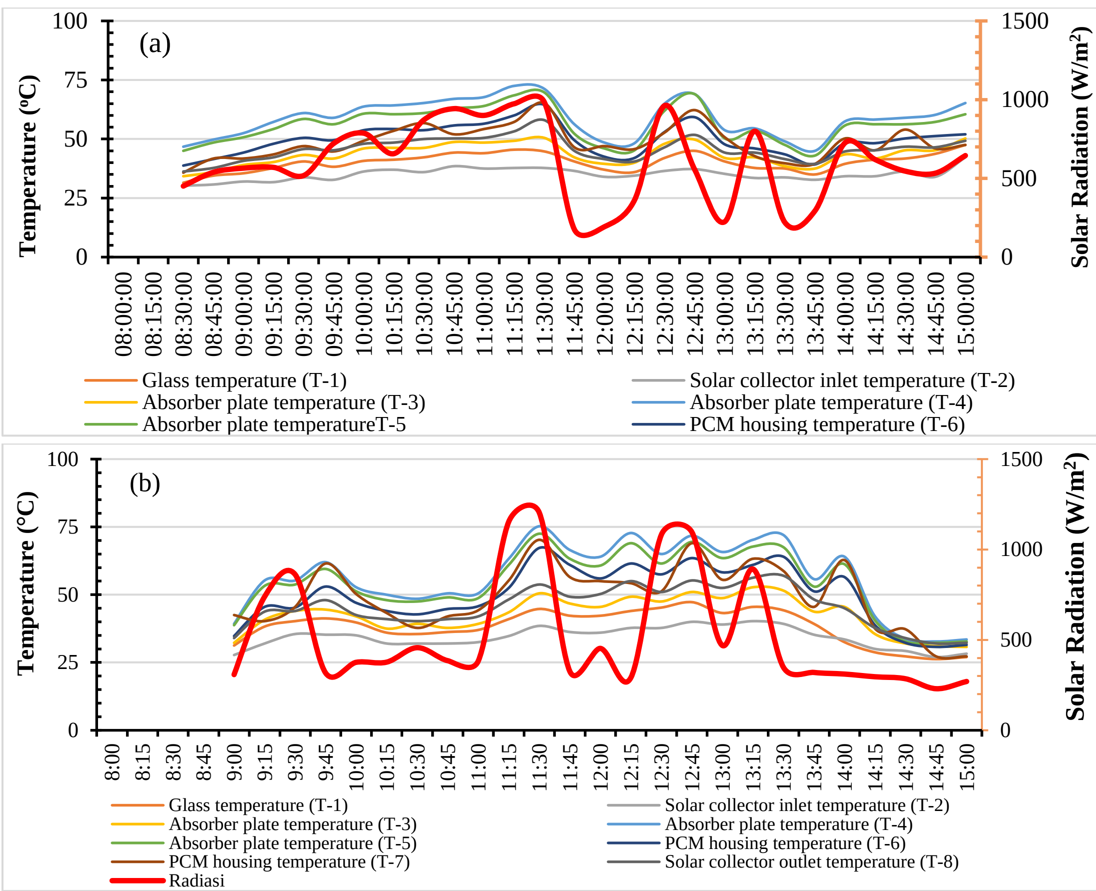

Figure 7. Solar radiation and temperature of glass, collector, absorber plate, PCM housing: (a) Day 1, (b) Day 2

3.3. Thermal Behavior of Solar Drying System Components

The thermal response of the solar drying system components showed strong correlation with solar radiation intensity throughout the drying period (Figure 7). On both Day 1 and Day 2, the absorber plates (T-4 and T-5) reached the highest temperatures, exceeding 70 °C at peak solar radiation. These results confirm the effectiveness of absorber plates in capturing and converting solar energy into usable thermal energy, which is essential for heating the drying chamber.

The role of the PCM housing (T-6 and T-7) was evident in its gradual and sustained temperature increase throughout the day. The PCM absorbed excess thermal energy during peak radiation hours and gradually released it as radiation declined, maintaining consistent thermal conditions within the system. This thermal buffering effect helps ensure uninterrupted drying and protects the process from sudden temperature drops due to weather fluctuations.

3.4. Temperature Dynamics and Drying Performance in the Drying Chamber

Temperature monitoring inside the drying chamber revealed consistent heating patterns with operational temperatures ranging between 40 °C and 46 °C (Figure 8). These values align with the optimal drying temperature for Arabica, promoting effective moisture removal without compromising bean quality. The drying chamber maintained these temperatures despite changes in ambient solar input, supported by thermal storage and active airflow.

Among the trays monitored, sensor T-15 showed the highest and most consistent temperatures, suggesting more favorable exposure to hot airflow or positioning near the heated air outlet. This indicates possible variations in airflow distribution within the chamber, which may influence drying rate uniformity across different trays. Temperature differences between trays were more pronounced on Day 1 but became more uniform by Day 2, suggesting improved heat distribution as the system stabilized. This could be attributed to fully charged PCM storage and consistent solar input on Day 3, resulting in smoother thermal conditions.

Overall, the system successfully reduced drying time to approximately 14 h to reach a final moisture content below 12%. This duration is significantly shorter than traditional sun drying methods, which may take up to two weeks under uncontrolled outdoor conditions. Such improvement in drying efficiency not only accelerates processing time but also reduces microbial risks and post-harvest losses.

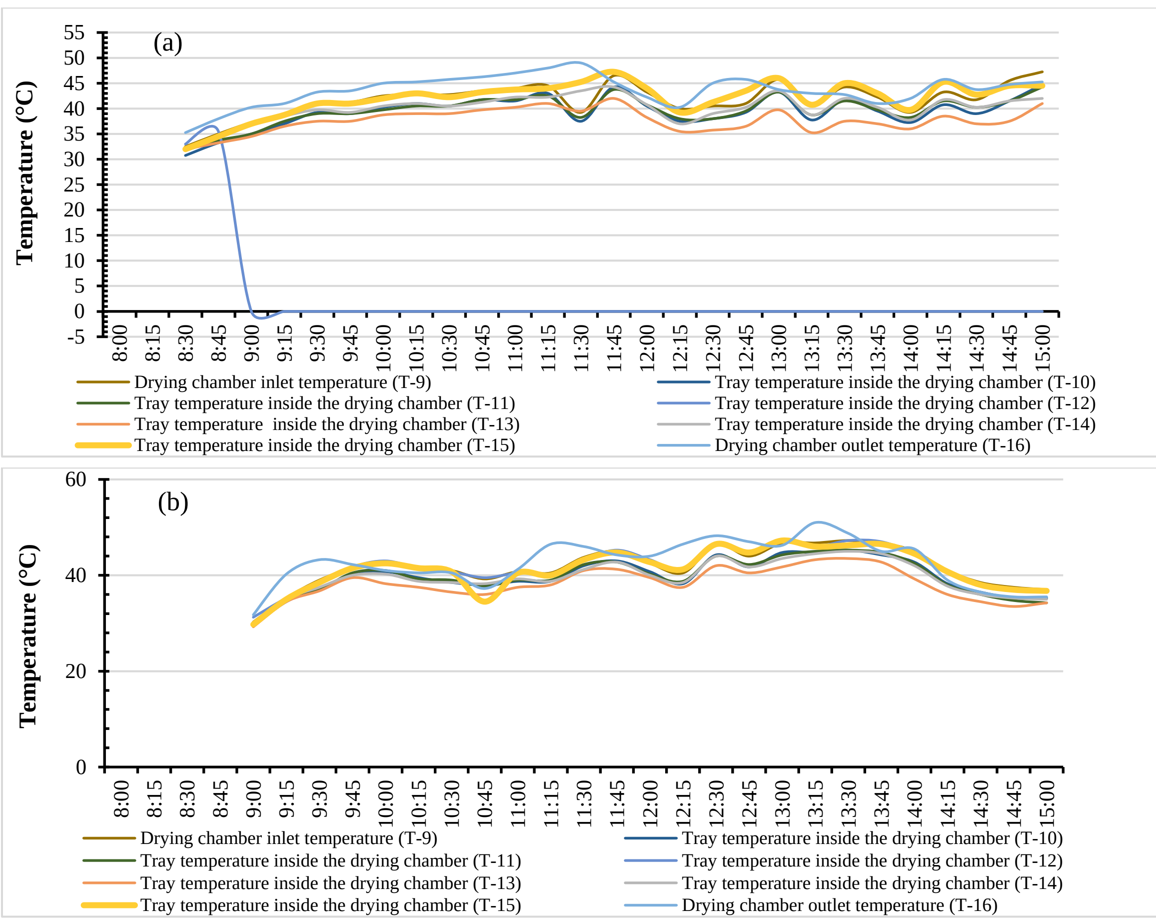

Figure 8. Temperature graph of drying chamber and trays: (a) Day 1, (b) Day 2

3.5. Moisture Content Profile and Drying Rate Analysis

The drying process of Arabica coffee beans in the solar drying chamber exhibited significant differences in moisture reduction rate between Day 1 and Day 2. Drying performance was analyzed according to the following equation.

$$\text{Drying Rate} = \frac{M_{t+1} - M_t}{t_{t+1} - t_t} \tag{1}$$

where $M_{t=}$ material mass at time t, M_{t+1}= material mass at time $t + 1$, t is time in hour.

The difference in drying rates can be attributed to environmental and system conditions on each day. On Day 1, although solar radiation intensity was lower, the drying chamber temperature was maintained above 40 °C due to the thermal insulation and heat storage effect of the PCM. As a result, the drying process remained stable, albeit with a slower moisture reduction. In contrast, Day 2 experienced higher solar radiation, leading to a significant increase in collector and chamber temperatures. The absorber plate reached temperatures 72 °C during midday, enhancing heat transfer and resulting in faster moisture evaporation. This was reflected in the drying rate peaking during the third hour.

Within two days, the final moisture content was successfully reduced to below 12.8% (Figure 9), in accordance with storage standards for green coffee beans. On both testing days, the moisture content was successfully reduced to below 12.8%, which is still in line with the international green storage standard (10 until 12%) and the maximum limit set by SNI 01-2907-2008, which is 12.5%. This indicates that the final moisture content met both national and international quality standards. This demonstrates that the solar drying system, combined with PCM and high-speed constant airflow, can maintain effective performance under varying weather conditions. These findings also highlight the importance of temperature stability, airflow direction, and thermal storage capacity in determining drying effectiveness and efficiency. The differences in drying rate profiles between the two days provide valuable insights for further system optimization, including drying chamber design, PCM volume, and operational time settings.

The graph in Figure 9 presents the moisture content reduction of Arabica beans over a drying period from 08:00 to 15:00 on Day 1 and Day 2. The drying process was carried out in a solar drying chamber equipped with a thermal collector and forced convection system, operating at a constant airflow velocity of 9.2 m/s. These equations show that the drying rate on Day 2 (1.5381%/hour) was significantly higher than on Day 1 (0.875%/hour). This result aligns with the thermal data reported by Mbakouop *et al.* (2023), where Day 2 exhibited better solar radiation stability, higher chamber temperatures, and more effective thermal performance from the absorber plate and PCM system.

On Day 1, despite lower solar radiation intensity, the system maintained drying temperatures above 40 °C due to the thermal insulation and heat storage effect of PCM, as stated by Abdissa *et al.* (2023) and Siagian *et al.* (2024b). However, the drying rate was slower, resulting in a more gradual decline in moisture content. On Day 2, the more rapid decrease in moisture content indicates a higher heat and mass transfer rate, likely due to improved solar radiation, better heat absorption by the aluminum absorber plate, and more consistent chamber conditions. These factors contributed to a faster and more efficient drying process.

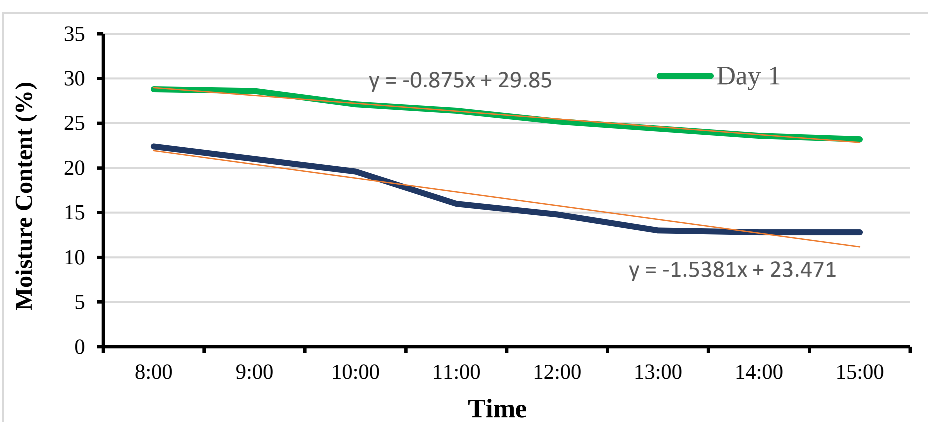

Figure 9. Drying rate profile of Arabica beans in the solar drying chamber on Day 1 and Day 2 (continuation of Day 1)

The final moisture content observed in both days approached the target level of below 12.8%, which is considered safe for green storage. The trend also reflects the chamber's ability to perform under variable weather conditions –a key strength emphasized for this dryer.

Overall, this analysis confirms the findings that the integration of solar thermal energy with high-velocity forced airflow and PCM storage significantly improves drying performance. Moreover, the difference between Day 1 and Day 2 highlights the importance of consistent solar radiation in achieving optimal drying efficiency.

Figure 10 illustrates the drying rate profile of Arabica beans over an 8-hour period for Day 1 and Day 2. The drying trials were conducted using a solar drying chamber operating at an airflow velocity of 9.2 m/s and an average chamber temperature of around 40–46.5 °C. On Day 1, the drying rate gradually increased during the early hours, peaking at 10.00 after 2 h with drying rate 22.45 g vapor/h, followed by gradual decrease for the remainder of the drying session. This steady and controlled drying profile indicates consistent internal conditions within the drying chamber, despite the lower solar radiation as reported by (Kebede *et al*., 2025). The presence of thermal insulation and the heat retention capability of the PCM contributed to maintaining stable drying rates throughout the day.

On Day 2, the drying rate profile was significantly more dynamic. A sharp spike occurred after 3 hour, with the drying rate reaching over 42 g vapor/h, indicating a burst of rapid moisture removal. This peak was influenced by optimal solar radiation and improved thermal efficiency of the system components. This sudden increase corresponds with the higher solar radiation and absorber plate temperatures for Day 2, which exceeded 72 °C. The peak was followed by a steep decline in drying rate, reaching near-zero after 7–8 h, suggesting that most free moisture had been evaporated early, and the drying entered the falling-rate phase dominated by bound moisture removal.

The contrast between both days confirms the influence of solar radiation intensity and thermal buffer performance on drying kinetics. Day 2 experienced a higher, but less uniform drying rate, while Day 1 offered a steadier drying pattern. These observations are consistent with the findings of (Firdissa *et al*., 2022), which highlight that higher solar radiation improves drying speed but may cause less consistent moisture reduction if not evenly distributed. The findings suggest that peak drying efficiency is achieved in the early hours (especially after around 2–4 h), particularly when supported by strong solar input. This information can inform future system improvements, such as optimizing airflow direction and adjusting PCM volume to smooth out extreme peaks and dips in drying rate.

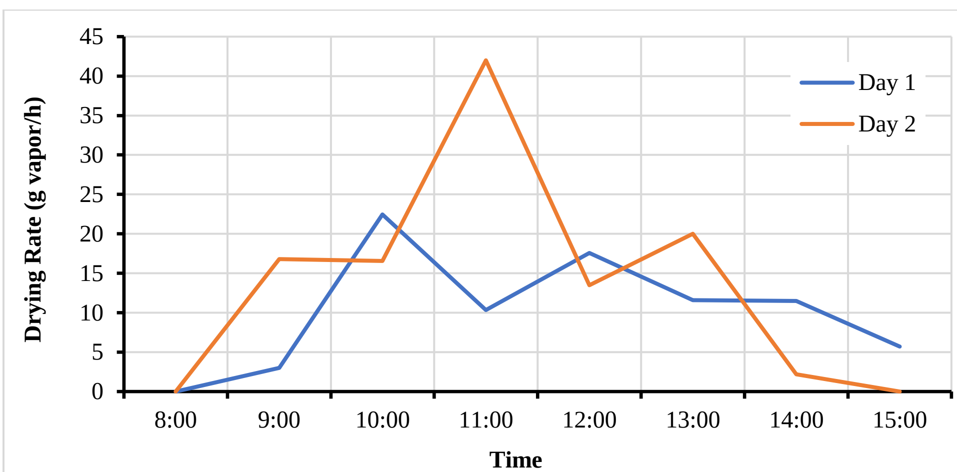

Figure 10. Drying rate of Arabica beans using solar drying chamber with 9.2 m/s air velocity on day 1 and day 2

4. CONCLUSION

This study confirms the effectiveness of a solar drying chamber integrated with a thermal collector, phase change material (PCM), and high-velocity forced convection in accelerating the drying process of Arabica coffee beans. Operating under a consistent airflow velocity of 9.2 m/s and average chamber temperatures ranging from 40 °C to 46.5

°C, the system successfully reduced the beans' moisture content to below 12.8% in less than 14 h —significantly faster than traditional open sun drying methods. The integration of solar thermal energy, thermal energy storage using PCM, and controlled airflow offers a sustainable, efficient, and weather-resilient solution for post-harvest processing. Future developments should explore airflow optimization, increased PCM capacity, and advanced collector materials to further improve system performance and enable extended or even continuous drying cycles.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Research Centre for Energy Conversion and Conservation, BRIN for the provision of equipment and technical resources for this study. The authors also extend their sincere thanks to the Department of Mechanical Engineering, Widyatama University, for granting access to laboratory facilities and providing a supportive research environment.

REFERENCES

Abdelwahab, S.I., Tahaa, M.M.E., Jerah, A.A., Aljahdali, I.A., Oraibi, B., Alfaifi, H.A., Abdullah, S.M., Alzahrani, A.H., Oraibi, O., Babiker, Y., & Farasani, A. (2024). Coffee arabica research (1932–2023): Performance, thematic evolution and mapping, global landscape, and emerging trends. *Heliyon, **10(16)***, e36137. https://doi.org/10.1016/j.heliyon.2024.e36137

Abdissa, Z. K., Tola, Y. B., Taye, A. H., & Mohammed, H. H. (2023). Harmonizing drying time, layer thickness, and drier zones for drying kinetics: Quality and safety of solar tunnel-dried wet-processed parchment coffee (*Coffea arabica* L.). *International Journal of Food Science*, *2023*, 1–16. https://doi.org/10.1155/2023/6677592

Acar, C., Dincer, I., & Mujumdar, A. (2022). A comprehensive review of recent advances in renewable-based drying technologies for a sustainable future. *Drying Technology, **40***, 1029–1050. https://doi.org/10.1080/07373937.2020.1848858

Al-Ghamdi, S., Alfaifi, B., Elamin, W., & Lateef, M.A. (2024). Advancements in coffee manufacturing: From dehydration techniques to quality control. *Food Engineering Reviews, **16***, 513–539. https://doi.org/10.1007/s12393-024-09383-5

Alves, G.E., Borém, F.M., Andrade, E.T., Isquierdo, É.P., Siqueira, V.C., & Dias, C.A. (2020). Influence of different temperatures and airflows on drying of natural and pulped coffee. *Engenharia Agrícola, **40***(2), 192–200. https://doi.org/10.1590/1809-4430-eng.agric.v40n2p192-200/2020

Andrade, P.S., Duarte, C.R., & Barrozo, M.A.S. (2024). Improving the quality of Arabica coffee (*Coffea arabica* L.) through innovative optimization of roto-aerated drying. *Innovative Food Science & Emerging Technologies, **96***, 103770. https://doi.org/10.1016/j.ifset.2024.103770

Moon, S.A., Wongsakul, S., Kitazawa, H., & Saengrayap, R. (2024). Influence of post-harvest processing and drying techniques on physicochemical properties of Thai Arabica coffee. *AgriEngineering, **6(3)***, 2198–2213. https://doi.org/10.3390/agriengineering6030129

Bacsi, Z., Fekete-Farkas, M., & Ma'ruf, M.I. (2022). Coffee yield stability as a factor of food security. *Foods, **11(19)***, 3036. https://doi.org/10.3390/foods11193036

Baqueta, M.R., Diniz, P.H.G.D., Pereira, L.L., Almeida, F.L.C., Valderrama, P., & Pallone, J.A.L. (2024). An overview on the Brazilian *Coffea canephora* scenario and the current chemometrics-based spectroscopic research. *Food Research International, **194***, 114866. https://doi.org/10.1016/j.foodres.2024.114866

Coelho, E.G., Bertarini, P.L.L., Gomes, M.S., Amaral, L.R., Zotarelli, M.F., Santos, L.D., & Santana, R.C. (2024). Physicochemical and sensory properties of Arabica coffee beans of Arara cv. dried using different methods. *Foods, **13***(5), 642. https://doi.org/10.3390/foods13050642

Daş, M., Alıç, E., & Akpinar, E.K. (2021). Numerical and experimental analysis of heat and mass transfer in the drying process of the solar drying system. *Engineering Science and Technology, an International Journal, **24(1)***, 236-246. https://doi.org/10.1016/j.jestch.2020.10.003

Duque-Dussán, E., Sanz-Uribe, J.R., & Banout, J. (2023). Design and evaluation of a hybrid solar dryer for postharvesting processing of parchment coffee. *Renewable Energy, **215**,* 118961. https://doi.org/10.1016/j.renene.2023.118961

Firdissa E., Mohammed A., Berecha G., Garedew W. (2022). Coffee drying and processing method influence quality of arabica coffee varieties (*Coffea arabica* L.) at Gomma I and Limmu Kossa, Southwest Ethiopia. *Journal of Food Quality*, ***3***, 1–8. https://doi.org/10.1155/2022/9184374

Freitas, V.V., Borges, L.L.R., Vidigal, M.C.T.R., Santos, M.H., & Stringheta, P.C. (2024). Coffee: A comprehensive overview of origin, market, and the quality process. *Trends in Food Science & Technology,* ***146***, 104411. https://doi.org/10.1016/j.tifs.2024.104411

Girma, B. (2023). The impact of climate change on coffee processing: A review. *Agriculture, Forestry and Fisheries*, ***12***(4). https://doi.org/10.11648/j.aff.20231204.14

Jawo, T.O., Kyereh, D., & Lojka, B. (2023). The impact of climate change on coffee production of small farmers and their adaptation strategies: A review. *Climate and Development*, ***15***(2), 93–109. https://doi.org/10.1080/17565529.2022.2057906

Jha, A., & Tripathy, P.P. (2024). Performance evaluation and finite element modeling of heat, mass, and fluid flow inside a hybrid solar dryer during drying of paddy grains. *Frontiers in Food Science and Technology*, ***4***, 1411956. https://doi.org/10.3389/frfst.2024.1411956

Kebede, A.Y., Tigabu, M.T., Admase, A.T., & Bezie, A.J. (2025). Performance evaluation of diminutive solar dryer for drying of green coffee beans: In Ethiopian highlands. *Case Studies in Thermal Engineering*, **65**, 105653. https://doi.org/10.1016/j.csite.2024.105653

Kamarulzaman, A., Hasanuzzaman, M., & Rahim, N.A. (2021). Global advancement of solar drying technologies and its future prospects: A review. *Solar Energy*, ***221***, 559–582. https://doi.org/10.1016/j.solener.2021.04.056

Martinius, M., Fauzi, A., & Resti, Z. (2022). Post-harvest fungal infection in *Arabica coffee beans* (*Coffea arabica* Linnaeus) in the coffee center of West Sumatra Province, Indonesia. *Jurnal Proteksi Tanaman*, ***6***(2), 1–10. https://doi.org/10.25077/jpt.6.2.1-10.2022

Mbakouop, A.N., Tchakounté, H., Ankungha, A.I., & Fapi, C.B.N. (2023). Experimental performance analysis of a mixed forced convection solar dryer: Application to cocoa bean drying. *Solar Energy*, ***257***, 110–124. https://doi.org/10.1016/j.solener.2023.04.010

Meja, E.M., Dubbe, S.K., Bekele, A., Wolde, K.F., & Adaramola, M.S. (2025). Investigating the performance and optimization of solar coffee drying technologies—A systematic review. *Journal of Food Processing and Preservation*, ***2025***(1), 7907660. https://doi.org/10.1155/jfpp/7907660

Pancsira, J. (2022). International coffee trade: A literature review. *Journal of Agricultural Informatics*, ***13***(1). https://doi.org/10.17700/jai.2022.13.1.654

Pandey, S., Kumar, A., & Sharma, A. (2024). Sustainable solar drying: Recent advances in materials, innovative designs, mathematical modeling, and energy storage solutions. *Energy*, ***308***, 132725. https://doi.org/10.1016/j.energy.2024.132725

Septianissa, S., Hadining, W.N., & Chandrasari, A.Z. (2025). Mechanical and microstructural effects of varying welding currents in GTAW of 7075-T62 aluminum. *Jurnal Polimesin*, ***23***(1), 32–37. https://doi.org/10.30811/jpl.v23i1.6060

Septianissa, S., & Chandrasari, A.Z. (2024). Corrosion rate of ASTM A53 steel in seawater influenced by variation in concentration of *Mangifera indica* L. peel extract. *Journal of Applied Engineering and Technological Science (JAETS)*, ***6***(1), 550–560. https://doi.org/10.37385/jaets.v6i1.5182

Siagian, P., Napitupulu, F.H., Ambarita, H., Sihombing, H.V., Sibagariang, Y.P., & Siagian, H.S. (2024a). The effect of varying the air flow in a solar collector on the quality of *Arabica coffee beans*. *Fluids*, ***9***(3), 75. https://doi.org/10.3390/fluids9030075

Siagian, P., Napitupulu, F.H., Ambarita, H., Sihombing, H.V., Sibagariang, Y.P., & Siagian, H.S. (2024b). the effect of varying the air flow in a solar collector on the quality of Arabica coffee beans. *Fluids*, ***9***(3), 75. https://doi.org/10.3390/fluids9030075

Siles, P., Cerdán, C.R., & Staver, C. (2022). Smallholder coffee in the global economy—A framework to explore transformation alternatives of traditional agroforestry for greater economic, ecological, and livelihood viability. *Frontiers in Sustainable Food Systems*, ***6***, 808207. https://doi.org/10.3389/fsufs.2022.808207

Soeswanto, B., Wahyuni, N.L.E., & Prihandini, G. (2021). The development of coffee bean drying process technology – A review. *Advances in Engineering Research: Proceedings of the 2nd International Seminar of Science and Applied Technology (ISSAT 2021)*, ***211***, 142–147. https://doi.org/10.2991/aer.k.211106.026

Izuka, U., Ojo, G.G., Ayodeji, S.A., Ndiwe, T.C., & Ehiaguina, V.E. (2023). Powering rural healthcare with sustainable energy: A global review of solar solutions. *Engineering Science & Technology Journal,* *4*(**4**), 190–208. https://doi.org/10.51594/estj.v4i4.582

Vesković, S. (2025). In the global food system: Addressing food losses, waste, and safety. In *Natural food preservation: Controlling loss, advancing safety,* 5–58. https://doi.org/10.1007/978-3-031-85089-9_2