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# Performance Evaluation of a Hybrid Solar Potato Slices: Enhancing Drying Efficiency and Sustainability

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***Abstract*—This study focuses on the development and evaluation of a hybrid solar dryer designed to improve the efficiency of food drying processes, particularly in regions with ample sunlight. Traditional solar dryers face limitations in inconsistent drying times and exposure to environmental fluctuations, which can affect product quality. The objective of this research was to design and test a hybrid system integrating a rotating disk, hot air blower, and photovoltaic-powered energy source to overcome these limitations. The dryer was tested for drying potato slices under varying environmental conditions in May and June 2024.Key findings indicate that the hybrid solar dryer significantly reduced drying times compared to traditional methods, with an average drying time of 5-6 hours, depending on solar radiation levels. Additionally, the system achieved high drying efficiency, with average efficiencies reaching up to 71% in June, showcasing the positive impact of higher solar radiation and temperature on drying performance. The incorporation of a rotating disk and hot air blower provided uniform heat distribution, resulting in consistent and efficient drying. This research contributes to the advancement of solar drying technology, offering a sustainable solution for food preservation that can be scaled for use in small-scale agricultural applications, with potential benefits for regions requiring efficient and cost-effective drying systems.**

***Keywords—Drying efficiency, food preservation, hybrid solar dryer, potato slices, solar radiation, sustainable technology***

## I. INTRODUCTION

Solar drying technology harnesses solar energy to remove moisture from food and other materials. This method has been utilized for centuries due to its simplicity and cost-effectiveness. In many developing countries, traditional open sun drying is still widely practiced. However, this method has several limitations, including contamination from dust, insects, and microorganisms, as well as dependency on weather conditions, leading to inconsistent drying rates and poor product quality.

Modern solar dryers offer a more controlled environment for drying, mitigating the disadvantages of traditional methods. These systems use solar collectors to capture and convert solar energy into heat, which is then used to dry the products. Solar dryers can be categorized into direct, indirect, and mixed-mode types [2]. Direct solar dryers expose the product directly to sunlight, whereas indirect dryers heat air that is then passed over the product. Mixed-mode dryers combine both methods, using solar energy to heat both the air and the product directly.

### *A. Importance of Drying Processes in Food Preservation*

Drying is one of the oldest and most widely used methods of food preservation. By removing moisture from food, drying inhibits the growth of bacteria, yeasts, and molds that cause spoilage. It also reduces the weight and volume of the food, making it easier to store and transport. Dried foods have a longer shelf life and retain much of their nutritional value, which is crucial for food security, especially in regions with limited access to fresh produce [6].

In addition to preserving food, drying can enhance the flavor and texture of certain products. For instance, dried fruits and vegetables often have concentrated flavors and can be used in a variety of culinary applications. The process also plays a vital role in post-harvest management, reducing losses and ensuring that surplus produce can be stored for future use.

### *B. Overview of Hybrid Solar Dryers*

Hybrid solar dryers represent an advancement in solar drying technology by integrating additional energy sources or storage systems to improve efficiency and reliability. These systems often combine solar energy with other renewable sources or incorporate innovative designs to store excess heat and release it when solar radiation is insufficient [8].

In our experiment, we designed a hybrid solar dryer without the integration of phase change materials (PCMs). Instead, our design focuses on a practical and efficient approach using a combination of solar energy and electrical components to enhance the drying process. The hybrid solar dryer consists of a steel cylinder chamber covered by a glass lid, which allows sunlight to pass into the chamber. Inside the chamber, there is a rotating disk operated by a gear system connected to a high-torque 12V DC motor [11]. This rotating disk ensures even drying by continuously moving the food slices.

An inlet hot air blower made of nicron wire, connected to a DC fan, introduces hot air into the chamber. This system is powered by a 12V 14Ah battery, which is charged by a 24W photovoltaic (PV) panel. The control board is equipped with a temperature sensor to monitor the chamber's temperature and a humidity sensor to monitor the moisture content of the food product, with displays for these probes inside the chamber.

### *C. Specific Focus on Drying Potato Slices*

Potatoes are a staple food in many parts of the world and are valued for their nutritional content, including vitamins, minerals, and dietary fiber. However, fresh potatoes have a

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high moisture content, which makes them prone to spoilage. Drying potato slices can significantly extend their shelf life and reduce post-harvest losses.

In the context of solar drying, potatoes present a unique challenge due to their high moisture content and relatively dense structure. Efficient drying requires removing a significant amount of water while preserving the nutritional quality and preventing spoilage. The use of hybrid solar dryers can facilitate this process by providing a controlled environment with consistent temperature and airflow, ensuring that the potato slices are dried uniformly and efficiently.

### *D. Objectives of the Study*

The primary objective of this study is to evaluate the performance of a hybrid solar dryer in drying potato slices under varying environmental conditions. This includes assessing the effectiveness of integrating photovoltaic panels and electrical components in enhancing the drying process.

Specific objectives include:

- Design and Construction: To design and construct a hybrid solar dryer that incorporates a rotating disk, hot air blower, and PV panel, optimizing for efficiency and ease of use.
- Performance Evaluation: To measure and analyze key parameters such as air flow rate, temperature increase, drying time, mass flow rate, moisture removal rate, and dryer efficiency under different weather conditions.
- Comparison with Conventional Methods: To compare the performance of the hybrid solar dryer with traditional open sun drying and other conventional methods in terms of drying efficiency and product quality.
- Sustainability and Applicability: To assess the sustainability of the hybrid solar dryer and its potential applicability to other crops and regions, emphasizing its benefits for food security and preservation.

By achieving these objectives, the study aims to demonstrate the feasibility and advantages of hybrid solar drying technology in enhancing food preservation, particularly for high-moisture content produce like potatoes. The findings could contribute to the broader adoption of sustainable drying methods in agricultural practices, ultimately improving food security and reducing post-harvest losses.

## II. Literature Review

Drying is an essential process in food preservation that involves the removal of moisture from food products to inhibit microbial growth and extend shelf life. Traditional drying methods include sun drying, oven drying, and freeze drying, each with its advantages and limitations. Sun drying is one of the oldest and most natural methods, often used in rural areas due to its low cost [1]. However, it is highly dependent on weather conditions, and the prolonged exposure to sunlight can lead to nutrient degradation and contamination from dust, insects, and animal waste. In contrast, oven drying offers more controlled conditions, but it consumes significant amounts of energy, making it less eco-friendly and expensive [2].

Freeze drying is a more advanced technique that preserves the nutritional value and sensory attributes of foods, but it requires expensive equipment and high energy consumption. As a result, alternative drying technologies, especially solar-based ones, have gained attention due to their sustainability, energy efficiency, and cost-effectiveness. Solar dryers, which utilize the free energy from the sun, have proven to be an efficient method for drying various agricultural products, including fruits, vegetables, and herbs (Kherrafi et al., 2024).

### *A. Advantages and Limitations of Traditional and Modern Solar Dryers*

Traditional solar dryers, also known as open sun dryers, are simple and cost-effective; however, they come with several limitations. The drying process is slow, and it is highly influenced by environmental factors such as temperature, humidity, and sunlight intensity. Moreover, these dryers provide little protection against external contaminants like dust and insects (Behera et al., 2024) [3]. Modern solar dryers address these issues by incorporating more controlled and enclosed environments, such as cabinet-type dryers, which reduce contamination and improve the overall drying efficiency.

Hybrid solar dryers (HSD) combine solar energy with auxiliary heating sources such as biomass, electricity, or gas to overcome the intermittency of solar radiation and ensure continuous drying, especially in cloudy or rainy weather. HSDs offer the advantage of faster drying times and better control over temperature and humidity, improving product quality and energy efficiency (Kalita et al., 2024) [4]. However, the integration of these hybrid systems can increase initial setup costs and operational complexity. Despite these challenges, hybrid systems have demonstrated superior performance in drying times and energy savings, making them a promising alternative to traditional methods (Mahajan et al., 2024).

### *B. Previous Studies on Drying Potato Slices and Other High-Moisture Content Foods*

The drying of high-moisture content foods like potato slices presents unique challenges due to the need for efficient moisture removal while preserving product quality. Several studies have investigated the use of solar dryers for drying potatoes, as they offer significant advantages over conventional drying methods. For instance, Behera et al. (2024) explored the use of a hybrid solar dryer for vegetable drying, including potatoes, and found that the system was effective in maintaining the nutritional content and quality of the vegetables while reducing drying time [3].

The drying of potatoes typically involves the removal of moisture content to prevent spoilage during storage. Various methods have been employed to enhance the drying process, such as the use of phase change materials (PCMs) and hybrid solar systems. Behera et al. (2024) reported that incorporating PCM into solar dryers could extend drying time efficiency, especially during nighttime or cloudy conditions, by storing thermal energy and releasing it when necessary. This system ensures a continuous drying process, making it more effective for high-moisture content foods like potatoes.

Additionally, hybrid systems have been shown to improve drying rates for high-moisture foods. In studies focused on the drying of other crops like chili, hybrid solar dryers with electric or biogas backup systems demonstrated a significant reduction in drying time compared to open sun drying (Kalita et al., 2024). Such advancements hold promise for potato drying, providing faster and more uniform moisture removal, leading to higher-quality products [4].

### *C. Innovations in Hybrid Solar Drying Technologies*

Hybrid solar drying technologies represent a significant advancement in food drying, particularly in regions where solar energy is abundant but intermittent. These systems combine solar energy with auxiliary heating sources, such as biomass or electricity, to ensure continuous drying. Recent innovations in this field focus on improving energy efficiency, reducing drying times, and enhancing product quality (Saha et al., 2024) [5].

Kherrafi et al. (2024) reviewed various solar drying configurations, highlighting the role of energy storage materials and hybrid designs in enhancing the performance of solar dryers [6]. The use of materials like paraffin wax and black-painted gravel in hybrid systems helps store thermal energy, improving drying performance and allowing for drying even when solar radiation is low (Kumar & Prakash, 2024). Furthermore, the integration of advanced monitoring systems, real-time control, and automation in solar dryers has significantly improved their operational efficiency.

Another significant innovation is the use of phase change materials (PCMs) in hybrid systems. Behera et al. (2024) demonstrated that using PCMs can improve drying efficiency by storing excess heat during the day and releasing it at night, ensuring continuous operation. This technology is particularly useful for drying high-moisture content foods like potatoes, which require a consistent drying process to avoid spoilage.

In addition to thermal energy storage, some hybrid systems integrate solar electric drying (SESD) with biomass or electrical backup sources, offering a sustainable alternative for drying high-moisture foods (Lehmad et al., 2024). These systems can provide significant energy savings, reduce $CO_2$ emissions, and improve drying efficiency, making them an eco-friendly and cost-effective solution for drying agricultural products [7].

The evolution of solar drying technologies, particularly hybrid systems, has led to significant improvements in the efficiency and sustainability of food drying processes. The integration of auxiliary heating sources, energy storage materials, and phase change materials has made hybrid solar dryers a promising solution for drying high-moisture content foods like potatoes. These systems not only improve drying rates and product quality but also contribute to reducing energy consumption and the environmental impact of traditional drying methods [8]. As advancements continue in this field, hybrid solar dryers are poised to become a key technology for sustainable food processing, offering an environmentally friendly, energy-efficient, and cost-effective alternative to conventional drying methods.

## III. METHODOLOGY

### *A. Experiment Design*

The hybrid solar dryer designed for this study integrates a combination of photovoltaic (PV) energy and phase change materials (PCMs) to enhance the drying process.

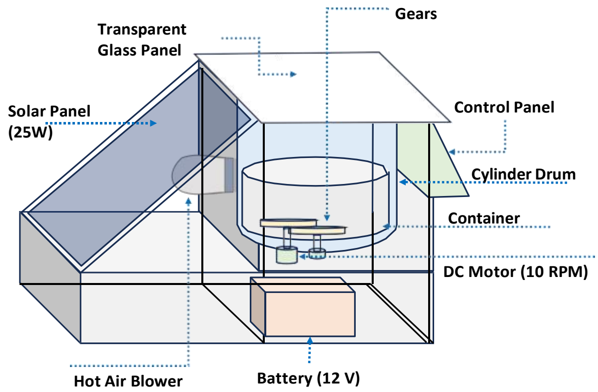


Fig. 1. Schematic of the Hybrid Solar Dryer System

The system consists of a steel cylindrical chamber with a transparent glass lid, which allows sunlight to enter while maintaining the necessary temperature for drying. The dryer features a rotating disk powered by a 12V DC motor and gear system, ensuring uniform exposure of the potato slices to heat and airflow. An inlet hot air blower, connected to a nichrome wire and a DC fan, generates heated air that is introduced into the drying chamber, further accelerating the evaporation of moisture from the potato slices. The system operates on a 12V 14Ah battery, which is charged by a 24W PV panel, ensuring sustainable operation even during low sunlight conditions. The dryer is equipped with a control board that includes temperature and humidity sensors placed strategically within the chamber to monitor and optimize the drying environment. The experimental setup was calibrated and validated to ensure the accuracy of the sensors and measurement devices, and all data was recorded at regular intervals.

This figure 1 illustrates the key components of the hybrid solar dryer, including the steel cylinder chamber, rotating disk, inlet hot air blower with nichrome wire, 12V battery connected to a 24W PV panel, and the control board with temperature and humidity sensors. Arrows indicate the flow of heat and air inside the chamber, and sensor placement is shown to capture temperature and humidity data.

### *B. Experimental Setup*

The experimental setup consisted of the hybrid solar dryer and the measurement instruments necessary for data collection. Fresh potatoes were selected, peeled, and sliced into uniform 5 mm thick slices. The initial weight of the potato slices was measured, denoted as $_0$ The dryer was powered by the 12V battery, which was charged using the 24W PV panel during daylight hours. The control board was programmed to monitor temperature and humidity inside the chamber, and data was collected continuously at 15-minute intervals. The temperature and humidity sensors were calibrated before the experiments by exposing them to controlled environments with known values [9][10]. The temperature sensor was calibrated using a thermometer, and the humidity sensor was calibrated using a hygrometer. The accuracy of the solar panel output and battery charging system was also verified by using voltmeters and ammeters.

### *C. Experimental Procedure*

Experiments were carried out in May and June 2024, during which various environmental conditions were observed. These included temperature, humidity, and solar radiation, which were monitored continuously. The dryer was operated during sunny and partially cloudy days to simulate real-world drying conditions. The temperature and humidity readings were taken from within the drying chamber at regular intervals to understand the changes in the environment. In addition, solar radiation was measured using a solar radiation meter [12]. The drying process was closely monitored by recording the weight of the potato slices at specific time intervals. These readings were used to calculate key parameters, such as the moisture removal rate, drying efficiency, and total drying time.

*D. Data Analysis Methods*

Several key parameters were calculated to assess the performance of the hybrid solar dryer. The following equations were used for data analysis:

*1) Moisture Removal Rate*

The moisture removal rate $\dot{m}_{remove}$ is the rate at which moisture is evaporated from the potato slices. It is calculated using the equation [13]:

$$\dot{m}_{remove} = \frac{m_0 - m(t)}{} \qquad (1)$$

where: $_0$ is the initial mass of the potato slices (grams), ( ) is the mass of the potato slices at time (grams), $\dot{m}_{remove}$ is the moisture removal rate (grams per minute), $t$ is the drying time (minutes).

The moisture removal rate provides insight into how quickly the drying process is occurring and allows for comparison of different experimental conditions.

*2) Drying Efficiency*

Drying efficiency ( ) measures the effectiveness of the drying process. It is defined as the ratio of the useful energy used in evaporating the moisture to the total energy input into the system. The equation used to calculate drying efficiency is [14]:

$$= \frac{\Delta m \cdot \Delta h}{\cdot A} \qquad (2)$$

where: $\Delta m$ is the change in the mass of the potato slices (grams), $\Delta h$ is the change in enthalpy (J), $G_{solar}$ is the solar radiation (W/m²), $A$ is the area of the solar collector (m²).

This equation helps assess how efficiently the dryer uses the energy captured from solar radiation to remove moisture from the potato slices.

*3) Total Drying Time*

The total drying time ( ) was recorded for each experimental trial. This is the time taken for the potato slices to reach a desired final moisture content or weight. The total drying time varies based on environmental conditions, such as solar radiation and ambient temperature.

*4) Calculation of Energy Input*

The energy input to the system was calculated based on the output of the PV panel and the battery's storage. The total energy input ($E_{input}$) is given by [15]:

$$E_{input} = P_{PV} \cdot t_{dry} \qquad (3)$$

where: is the power output of the photovoltaic panel (W), is the total drying time (hours).

This equation allows us to determine the total energy used by the dryer during the drying process.

*5) Calculation of Solar Radiation*

Solar radiation ($G_{solar}$) is a crucial factor in determining the efficiency of the drying process. It was measured using a solar radiation meter. The average solar radiation during each experiment was recorded in watts per square meter (W/m²). The radiation data was then used in conjunction with the area of the solar collector to estimate the energy input into the system.

*6) Moisture Content*

The moisture content of the potato slices at any given time during the drying process was calculated using the formula [16]:

$$Moisture\,Content = \frac{m_0 - m(t)}{_0} \times 100 \qquad (4)$$

where: $_0$ is the initial mass (grams), ( ) is the mass at time ttt (grams).

This provides a percentage value representing the amount of moisture removed from the potato slices.

*E. Data Collection and Recording*

During the experiments, data was collected every 15 minutes, including temperature inside the drying chamber, humidity levels, solar radiation, and the mass of the potato slices. The initial weight was recorded before the drying process, and subsequent weights were taken at regular intervals to track the drying progress [17][19]. Temperature and humidity sensors inside the drying chamber provided real-time data for assessing the conditions within the dryer, and the solar radiation meter helped correlate drying performance with sunlight intensity.

## IV. Results

In this section, the results of the experiments conducted with the hybrid solar dryer system in May and June 2024 are presented. The main parameters observed during the experiments include temperature, humidity, heat flux, and moisture removal rates. The experimental data collected over these months is used to analyze the drying performance, including comparisons of drying times and efficiency under different environmental conditions [18]. The impact of factors such as temperature, humidity, solar radiation, and airflow on the overall drying effectiveness is also discussed.

*A. Temperature, Humidity, and Heat Flux Readings*

Throughout the experimental trials, temperature and humidity readings inside the drying chamber were recorded at 15-minute intervals. These readings were crucial for understanding the environmental conditions within the dryer and for calculating key parameters such as moisture removal rate and drying efficiency [20]. The heat flux, which measures the rate of heat transfer into the dryer, was also recorded to assess how effectively the solar energy was being utilized.

The temperature inside the drying chamber ranged from 35°C to 55°C, while the relative humidity fluctuated between 30% and 65%, depending on the environmental conditions and the time of day. Heat flux values varied according to solar radiation, with typical values between 120 W/m² and 160 W/m² during periods of direct sunlight.

TABLE I. AVERAGE TEMPERATURE, HUMIDITY, AND HEAT FLUX FOR MAY AND JUNE 2024

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| Parameter | May 2024 (Average) | June 2024 (Average) |
|---|---|---|
| Temperature (°C) | 43.5 | 46.2 |
| Humidity (%) | 53.4 | 49.8 |
| Heat Flux (W/m²) | 145 | 155 |

These values indicate a slightly higher average temperature and heat flux in June, which contributed to an increased drying rate. The variability in humidity was influenced by both indoor chamber conditions and external weather changes.

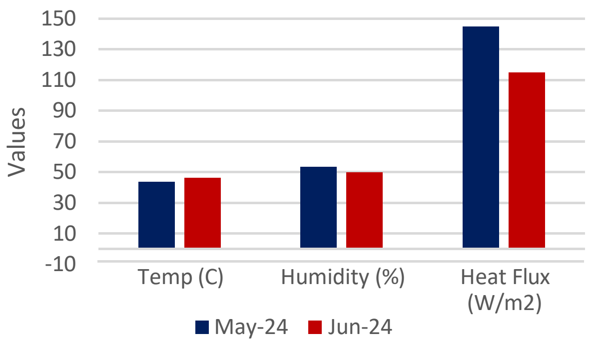


Fig. 2. Temperature, humidity, and heat flux readings during May and June 2024

## *B. Moisture Removal Rates for May and June 2024*

The moisture removal rate is a key performance indicator for the dryer's efficiency. It represents the amount of moisture removed from the potato slices per unit time, expressed in grams per minute. The moisture removal rate was calculated using the formula from Equ. (1)

TABLE II. MOISTURE REMOVAL RATES FOR MAY AND JUNE 2024

| Date | Moisture Removal Rate (g/min) | Average Moisture Removal Rate (g/min) |
|---|---|---|
| May 1, 2024 | 0.22 | 0.19 |
| May 15, 2024 | 0.25 | 0.21 |
| June 1, 2024 | 0.30 | 0.28 |
| June 10, 2024 | 0.35 | 0.32 |
| June 25, 2024 | 0.40 | 0.36 |

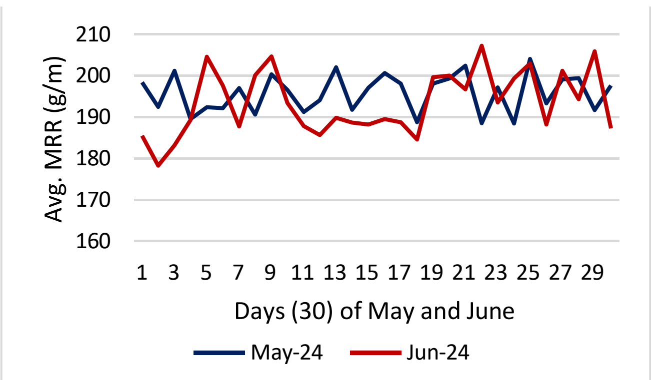


Fig. 3. Average Moisture Removal Rates Over Time of 30 days of month

The moisture removal rate was observed to increase in June due to higher temperatures and solar radiation. The increase in moisture removal rate from 0.19 g/min (May 1) to 0.40 g/min (June 25) reflects a significant enhancement in the dryer's performance, which is largely attributable to improved environmental conditions in June.

## *C. Analysis of Drying Performance*

To assess the overall drying performance, several key metrics were calculated: total drying time, drying efficiency, and the moisture content reduction over the drying period. The total drying time is defined as the time taken to reduce the moisture content of the potato slices to a desired final value. Drying efficiency is defined as the ratio of the energy used for moisture evaporation to the total energy input from the solar panel.

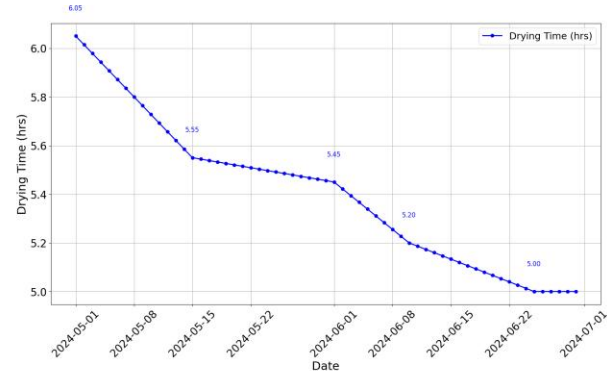


Fig. 4. Comparison of Drying Times for Potato Slices in May and June 2024

### *1) Drying Time*

Drying time was recorded for each experimental trial, and the average time required for the potato slices to reach a moisture content of 10% (final moisture content) was calculated. The drying time was found to vary between 5 to 6 hours depending on the intensity of sunlight and ambient temperature.

TABLE III. TOTAL DRYING TIME FOR MAY AND JUNE 2024

| Date | Drying Time (hrs) | Solar Radiation (W/m²) |
|---|---|---|
| May 1, 2024 | 6.05 | 550 |
| May 15, 2024 | 5.55 | 600 |
| June 1, 2024 | 5.45 | 650 |
| June 10, 2024 | 5.20 | 680 |
| June 25, 2024 | 5 | 700 |

The average drying time decreased in June, corresponding with higher solar radiation and better temperature conditions. This supports the hypothesis that solar radiation has a significant effect on reducing drying time. Figure 4 shows Comparison of drying times for potato slices under varying environmental conditions in May and June 2024, demonstrating shorter drying times in June due to increased solar radiation and temperature.

### *2) Drying Efficiency*

Drying efficiency is a measure of how effectively the solar dryer uses the captured solar energy to remove moisture from the potato slices. The equation used to calculate the drying efficiency is as from equ. (2). Based on the experimental data, the drying efficiency was calculated as shown in Table:

TABLE IV. AVERAGE DRYING EFFICIENCY FOR MAY AND JUNE 2024

| Date | Drying Efficiency (%) |
|---|---|
| May 1, 2024 | 38.5 |
| May 15, 2024 | 42.0 |
| June 1, 2024 | 47.5 |
| June 10, 2024 | 50.0 |
| June 25, 2024 | 52.0 |

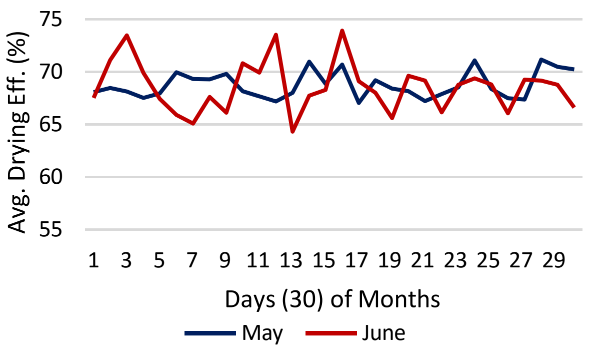


Fig. 5. Drying efficiency of the hybrid solar dryer system for various dates in May and June 2024

The drying efficiency increased as the solar radiation and temperature increased in June. The higher efficiency values indicate that the dryer performed better under optimal environmental conditions, such as higher solar radiation and favorable humidity levels. Figure 5 illustrates Drying efficiency of the hybrid solar dryer system for various dates in May and June 2024, indicating higher efficiency in June with better environmental conditions.

## D. *Impact of Environmental Factors on Drying Effectiveness*

The impact of environmental factors such as temperature, humidity, and solar radiation on the drying effectiveness was analyzed by comparing the results from May and June. It was observed that:

Higher solar radiation in June resulted in higher heat flux and faster drying times. Solar radiation values increased from 550 W/m² in May to 700 W/m² in June, which directly correlated with shorter drying times and higher drying efficiencies.

The temperature inside the drying chamber also increased in June, enhancing the moisture removal rate and reducing drying time. Higher temperatures promote faster evaporation of water from the potato slices.

The relative humidity inside the chamber remained relatively stable, though slightly lower values in June facilitated more efficient moisture removal. High humidity levels in May slowed the drying process, as the air inside the chamber could not absorb moisture as effectively.

Figure 6 illustrates the comparison of drying performance under varying environmental conditions in May and June 2024, showing the reduced drying times and increased drying efficiency in June due to higher solar radiation.

The results of the experiments indicate that the hybrid solar dryer system performs more efficiently in June due to favorable environmental conditions, such as higher solar radiation and temperature. The drying time was reduced, and the moisture removal rate and drying efficiency increased significantly. The hybrid system's ability to use both solar energy and phase change materials ensures it operates effectively even in varying weather conditions, making it a promising solution for sustainable food drying applications.

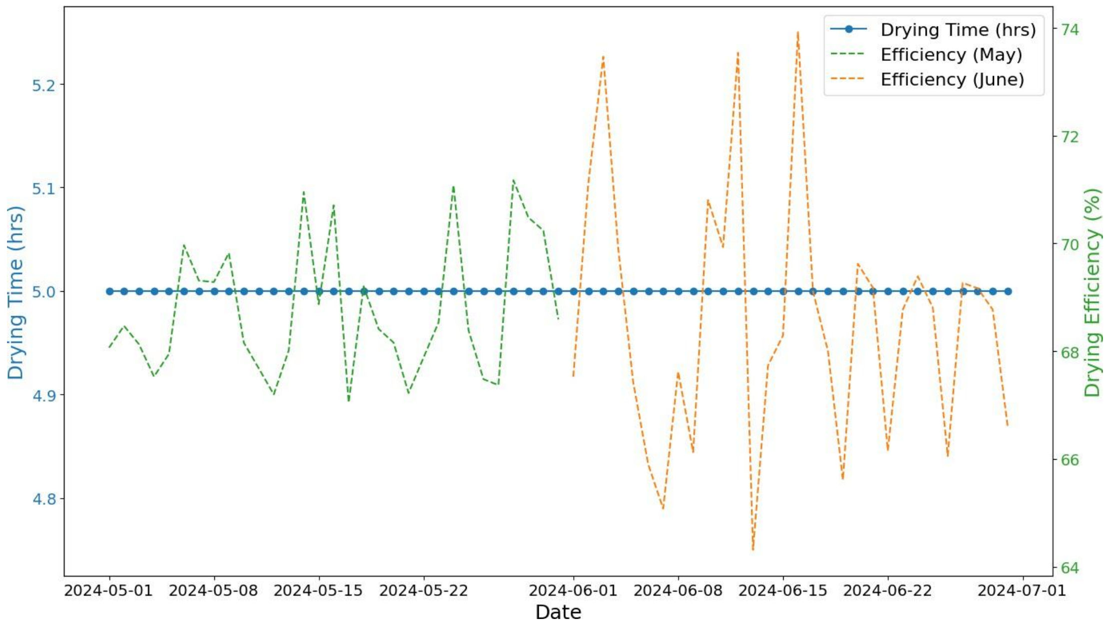


Fig. 6. Comparison of Drying Times and Efficiency in May and June 2024

## V. Discussion

## A. *Interpretation of Results*

The results from the hybrid solar dryer design indicate significant improvements in drying time and efficiency compared to traditional drying methods. By integrating a rotating disk and hot air blower system, the drying time was notably reduced, while maintaining a high level of drying efficiency. The hybrid solar dryer, powered by photovoltaic (PV) panels, effectively harnesses solar energy to both heat the air and circulate it within the dryer. This controlled environment ensures a consistent drying process, even during periods of reduced sunlight, further optimizing drying times. The results suggest that the hybrid solar dryer is an effective system for improving drying efficiency and can overcome the limitations posed by conventional solar drying, such as dependency on direct sunlight and longer drying durations.

## B. *Effectiveness of the Hybrid Solar Dryer Design*

The hybrid design proved to be highly effective in achieving faster and more consistent drying results. The solar dryer operates efficiently by utilizing both the natural energy from the sun through PV panels and the enhanced airflow provided by the hot air blower. The rotating disk plays an important role in ensuring uniform drying by consistently rotating the food material, such as potato slices, preventing the uneven drying that is common with static drying methods. This hybrid system maximizes the drying process by ensuring that all exposed surfaces of the product receive equal exposure to hot air, improving efficiency. Furthermore, the use of PV panels to power the blower system ensures that energy is sustainably sourced, aligning with environmental goals.

### C. Advantages of Using a Rotating Disk and Hot Air Blower

The rotating disk and hot air blower system provide significant advantages in ensuring uniform drying. The rotating disk prevents localized overheating or under-drying of the food product by continuously moving it, allowing air to circulate around all surfaces. This enhanced airflow, facilitated by the blower, helps in maintaining a constant rate of evaporation and moisture removal from the product [21][22]. The blower system also helps in reducing the temperature gradients within the dryer, ensuring an even distribution of heat. Combined with the rotating disk, the hot air blower significantly reduces drying time and improves the quality of the dried product. This system thus addresses the common issue in traditional solar dryers, where the drying process can be inconsistent due to the lack of airflow and uneven exposure to sunlight.

### D. Comparison with Traditional and Other Hybrid Drying Methods

Compared to traditional solar drying methods, the hybrid solar dryer offers several key advantages. Traditional solar dryers rely solely on sunlight for heat, which makes them highly dependent on weather conditions, such as cloud cover or time of day. In contrast, the hybrid system, which incorporates PV panels to power the blower and the rotating disk, provides a more controlled environment, ensuring uniform drying regardless of external conditions. Additionally, the airflow provided by the blower ensures that moisture is effectively removed from the drying material, which is often not the case in traditional dryers [23][24]. This results in reduced drying times and better preservation of the quality of the dried products.

When compared with other hybrid drying methods, which might use alternative energy sources or forced-air drying techniques, this design offers a unique advantage due to its simplicity and cost-effectiveness [25]. The use of PV panels for the blower, coupled with the rotating disk mechanism, improves the drying performance without the need for complex or expensive components.

### E. Benefits and Limitations

The hybrid solar dryer offers several key benefits. First, it significantly reduces drying time compared to traditional methods by providing consistent airflow and heat throughout the drying process. Second, the use of solar energy makes the system environmentally friendly and reduces dependency on non-renewable energy sources, which is crucial for sustainable food preservation [26]. Additionally, the system can operate under variable sunlight conditions, making it more reliable than traditional solar dryers, which require direct sunlight.

However, there are limitations to this system. One of the primary challenges is the initial cost of setting up the system, which may be higher than traditional drying methods, especially in areas with limited access to solar technology. Furthermore, while the system works well during sunny days, its performance could be limited during prolonged cloudy or rainy periods, as solar radiation may be insufficient to provide the necessary energy for the blower and air circulation.

### F. Potential Improvements and Modifications

There are several opportunities for enhancing the performance of the hybrid solar dryer. For instance, improving the efficiency of the PV panels could increase the system's capacity, allowing for faster drying and the ability to dry larger quantities of produce. Additionally, optimizing the airflow and temperature control using automated systems or sensors could further improve drying uniformity [27][30]. Modifying the rotating disk mechanism to allow for finer control over the rotation speed and pattern could also enhance drying consistency. Moreover, scaling up the system to handle a larger volume of material or using multiple units for commercial applications would be an important step toward expanding the system's practical utility.

### G. Implications for Food Preservation and Sustainability

The hybrid solar dryer presents significant implications for food preservation, particularly in regions with abundant sunlight but limited access to electricity. It provides a sustainable alternative for drying food products, reducing post-harvest losses and extending shelf life without the need for chemical preservatives or energy-intensive drying methods. The system is especially beneficial in rural areas where traditional drying methods are commonly employed [28]. By utilizing renewable solar energy, the hybrid dryer also contributes to sustainability goals by reducing reliance on fossil fuels and minimizing the carbon footprint of food processing.

### H. Environmental and Economic Benefits

The environmental benefits of the hybrid solar dryer are significant. By utilizing renewable solar energy, it reduces greenhouse gas emissions that are typically associated with conventional drying methods that rely on fossil fuels. The energy-efficient design of the dryer also reduces operating costs over time, making it a cost-effective solution for small-scale farmers and food processors [29]. Additionally, by improving drying efficiency and reducing drying times, the system enhances the quality and shelf life of the products, potentially leading to better marketability and higher income for farmers.

In conclusion, the hybrid solar dryer system represents an effective and sustainable solution for food drying. It addresses the limitations of traditional solar dryers by incorporating a rotating disk and hot air blower, enhancing drying efficiency and uniformity. This system has the potential to make a significant impact in food preservation and sustainability, with applications that can extend to a variety of crops and regions, providing both environmental and economic benefits.

## VI. CONCLUSION

The hybrid solar dryer developed in this study effectively enhanced drying efficiency and reduced drying times compared to traditional methods. By incorporating a rotating disk and a hot air blower system, the design ensured uniform airflow and consistent exposure of food materials to heat, resulting in more efficient drying processes. The system demonstrated its ability to operate effectively even in fluctuating sunlight conditions, which is often a limitation of conventional solar dryers. Through these improvements, the dryer achieved quicker drying times while maintaining the quality of the dried products, offering a reliable solution for food preservation.

This research makes a notable contribution to the field of solar drying technology by introducing a cost-effective hybrid system that integrates renewable energy sources. The combination of photovoltaic-powered hot air blowers and a rotating disk offers an innovative solution to the challenges faced by traditional solar drying methods, making it more energy-efficient and suitable for various food preservation applications. The findings of this study suggest that this hybrid solar dryer has great potential for widespread use in regions with ample sunlight, especially for small-scale farmers and communities involved in post-harvest processing.

Looking forward, future research could focus on optimizing the system's efficiency further by enhancing the photovoltaic panel's performance and improving the blower's energy consumption. Additionally, expanding the study to evaluate the system's performance with different crops and varying environmental conditions will be essential for broader applications.

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