Comparative Analysis of Drying Rate and Moisture Content Reduction in Cassava Peel Using Direct and Indirect Solar Drying Methods

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Abstract. Cassava peel, an abundant agro-industrial by-product, holds significant potential as a feedstock for biochar production. However, appropriate pre-treatment through drying is essential to improve energy efficiency during carbonization. This study aims to evaluate and compare the drying performance of direct and indirect solar drying methods in terms of drying rate and moisture content reduction. Cassava peel samples weighing 500 grams each were prepared through manual washing and draining without mechanical assistance. Drying tests were conducted over a 10-hour period at 2-hour intervals using both direct and indirect solar drying methods. Moisture content was measured gravimetrically based on mass loss over time, while the drying rate was calculated as the change in sample mass per unit surface area per unit time (kg/m²•h). The results showed that direct solar drying achieved a significantly higher drying rate, with a mean of 0.0990 kg/m²•h and a standard deviation of 0.0337. In contrast, indirect solar drying yielded a lower mean drying rate of 0.0256 kg/m²•h with a standard deviation of 0.0088, highlighting the impact of solar intensity on the drying process. Moisture content in the direct drying method decreased from 70% to 36% within 10 hours, while the indirect method only reduced it to 60% over the same period. These findings suggest that direct solar drying not only accelerates moisture removal but also exhibits greater drying dynamics, especially during the initial hours. The nearly fourfold increase in drying rate further underscores the effectiveness of direct exposure to sunlight in enhancing drying performance.

Keyword: Cassava peel, solar drying, drying rate, moisture content, renewable energy

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1 Introduction

Cassava peel, an abundant by-product from cassava processing, must undergo proper drying after washing to ensure efficient carbonization. Conventional drying using oven systems often poses limitations in terms of capacity, operational cost, and energy expenditure, making it less feasible for small-scale applications. Studies have demonstrated that solar drying, particularly direct and indirect solar dryers, can offer a cost-effective and scalable alternative [1], [2]. For instance, hybrid solar dryer systems—combining forced convection and solar heating—have been successfully implemented for cassava-based products, reducing dependency on grid electricity and lowering overall drying costs [3]. Numerous studies have reported successful implementations of solar drying for cassava products, with indirect solar dryers using natural convection achieving moisture reductions comparable to bench-top oven drying—within a soil moisture error margin of <0.2 kg/kg—and sustaining uniform temperature profiles during processing [4].

Recent advances in solar drying technology for agro-industrial biomass have emphasized the complementary benefits of both direct and indirect solar drying systems. While direct solar drying exposes the material to direct sunlight and achieves faster moisture removal, it may present challenges such as uneven drying or quality degradation for certain sensitive products. In contrast, indirect solar drying systems utilize heated air that passes over the material without direct sun exposure, resulting in more stable drying conditions that reduce the risk of contamination and better preserve product characteristics.

These systems have been particularly beneficial for high-moisture agricultural residues like cassava peels, where maintaining a balance between drying speed and final quality is essential. Furthermore, review studies across tropical agriculture highlight the scalability of solar dryers—from direct batch systems to passive cabinet designs—for a wide range of products, offering energy-efficient, low-cost, and environmentally sustainable drying options [5], [6]. These advances suggest that applying both direct and indirect solar drying to cassava peel could enhance biomass pre-treatment for biochar or biobriquette production, offering an accessible alternative to oven-based drying with minimal energy input and high product quality.

This research investigates the feasibility of replacing oven-based drying with direct and indirect solar drying methods for cassava peel intended for biochar or biobriquette production. Direct solar drying provides higher thermal intensity and faster moisture reduction, while indirect solar drying ensures more uniform and controlled drying conditions. This approach is consistent with best practices in biomass pre-treatment, where cassava peel is sun-dried or toasted to a final moisture content of 10–12% prior to carbonization [7]. Attaining this moisture range is critical not only for ensuring thermal efficiency during carbonization but also aligns with common storage standards, allowing the dried material to be preserved safely for 4 to 6 months without spoilage [8]–[10]. These findings highlight the relevance and urgency of adopting solar-based drying strategies within agro-industrial value chains.

2 Method

This study was conducted in three main stages to evaluate the drying performance and storage characteristics of cassava peel as a potential feedstock for biochar or biobriquette production. Cassava peel samples, weighing 500 grams each, were manually washed and drained without mechanical assistance. The drying process was conducted using two different methods: direct solar drying (with full sunlight exposure) and indirect solar drying (through a chamber that blocks direct sunlight). Each experiment was performed over a 10-hour period with 2-hour intervals. At each interval, the sample mass was recorded to determine the drying rate. The drying rate (R) was calculated using the standard gravimetric equation 1 [11].

$$R = \frac{W_i - W_{i+1}}{A \,.\, \Delta t} \tag{1}$$

where Wi and Wi+1 are the sample weights at the beginning and end of a time interval (in kg), A is the exposed surface area of the drying sample (in m²), and Δt is the drying time interval (in hours). This equation quantifies the mass of moisture removed per unit area and time, expressed in kg/m²•h. It allows for the comparison of drying kinetics between the two solar drying methods and serves as a performance indicator for evaluating drying efficiency.

Moisture content was determined at each time interval during the drying experiments using a gravimetric approach. The percentage of moisture content was calculated based on the difference between the initial mass and the remaining mass of the sample. This allowed assessment of the moisture reduction performance of both drying methods and helped identify suitable drying durations for optimal feedstock preparation.

A supplementary observation was conducted to evaluate the physical and mass changes of cassava peel when stored in open-air conditions without active drying. After the washing and manual draining process, a 500-gram sample of cassava peel was stored at ambient conditions and monitored daily over five consecutive days. The observation included visual assessments of the peel's color and texture, as well as daily weighing to track the reduction in mass. This qualitative and quantitative monitoring aimed to determine the point at which the peel exhibited excessive drying, darkening, or degradation in quality. The results from this stage were used to provide recommendations on the ideal time window for processing cassava peel before undesirable changes occur during storage.

3 Result and discussion

The drying rate of cassava peels using direct sunlight drying was observed over a 10-hour period at 2-hour intervals, showing a clear decreasing trend from 0.150 to 0.068 kg/m².h. During the first 2 to 4 hours, the drying rate dropped from 0.150 to 0.115 kg/m².h, indicating a rapid removal of free moisture from the surface—a stage known as the constant rate period. Between the 4th and 6th hour, the drying rate declined more noticeably to 0.087 kg/m².h, suggesting the onset of the falling rate period, where internal moisture begins to diffuse outward more slowly. From 6 to 10 hours, the rate continued to decline gradually, reaching 0.068 kg/m².h, which reflects the increased difficulty of removing bound water. This pattern is characteristic of drying behavior in hygroscopic materials such as cassava peel. The high initial drying rate in direct sunlight drying demonstrates efficient moisture removal early in the process, though with decreasing energy efficiency over time. These findings highlight the importance of optimizing drying duration to balance speed and energy use in open-sun drying systems.

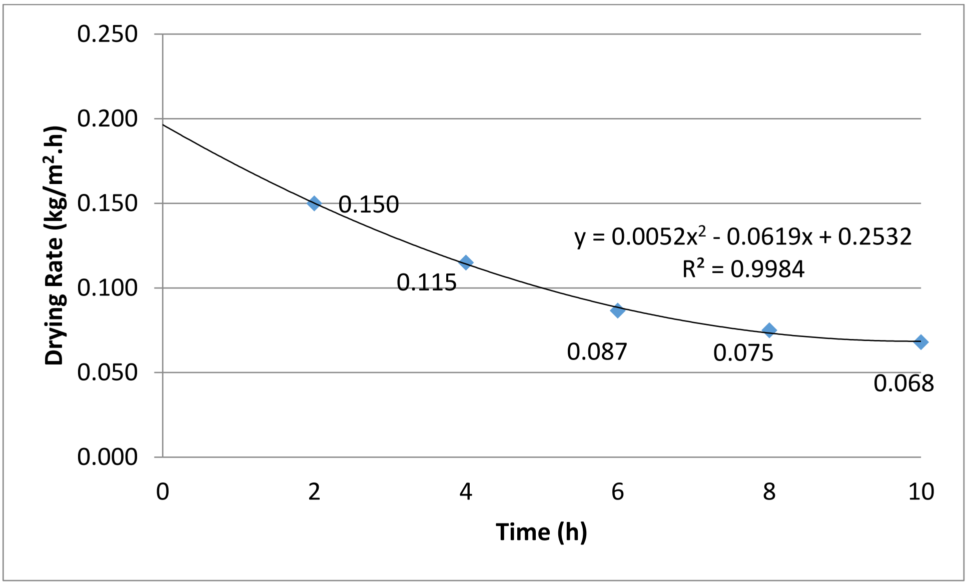

Fig. 1. Drying rate of cassava peel using direct solar

The drying rate of cassava peels using an indirect solar drying method was monitored over a 10-hour period with 2-hour intervals, as presented in figure 2. The drying rate decreased from 0.040 to 0.020 kg/m².h, with a significant drop observed in the first four hours. During the initial stage (2 to 4 hours), the drying rate fell from 0.040 to 0.028 kg/m².h, indicating the removal of surface moisture. From hour 6 to hour 10, the drying rate remained constant at 0.020 kg/m².h, suggesting the process had entered the falling rate period where moisture diffusion from the interior of the material became the limiting factor. Compared to direct sunlight drying, the drying rates in the indirect method were slightly lower, particularly during the early stages. This could be attributed to reduced radiant heat and airflow in the indirect system. Nonetheless, the consistency of the drying rate in later stages implies stable conditions and potentially more controlled drying. These results suggest that while indirect solar drying may be slower, it offers more uniform drying performance, which can be advantageous for preserving quality and preventing surface hardening.

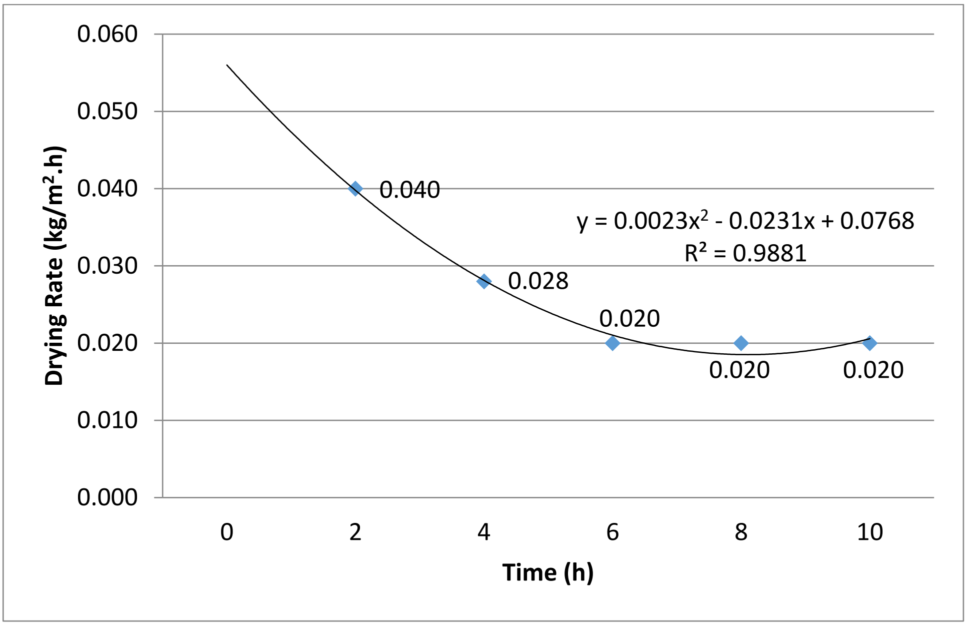

Fig. 2. Drying rate of cassava peel using indirect solar

A comparison of drying rates between direct and indirect sunlight drying methods for cassava peels over a 10-hour period reveals notable differences in drying behavior. In direct sunlight drying, the drying rate started higher at 0.150 kg/m².h and gradually declined to 0.068 kg/m².h, showing a steeper drop over time as surface moisture evaporated quickly in the early stages, as shown in figure 1. In contrast, indirect solar drying began with a lower drying rate of 0.040 kg/m².h, which dropped more gently and stabilized at 0.020 kg/m².h from the sixth hour onward. This indicates that while direct sunlight drying is faster in removing moisture, especially at the beginning, indirect drying offers a more controlled and consistent drying rate, particularly in the later stages. The lower and steadier rates observed in the indirect method suggest a slower but potentially more uniform drying process, which may help reduce the risk of case hardening and preserve product quality. Overall, direct sunlight drying is more time-efficient, whereas indirect drying may be better suited for applications requiring greater control over product drying conditions.

Table 1. Drying Rate Characteristics of Cassava Peel under Direct and Indirect Solar Drying Methods

Observed variable	N	Mean ± sdv
Drying Rate with direct solar (kg/m².h)	5	0.0990 ± 0.0337
Drying Rate with indirect solar (kg/m².h)	5	0.0256 ±0.0088

These findings suggest that direct solar drying not only accelerates moisture removal but also exhibits greater drying dynamics, especially during the initial hours. As shown in Table 1, the drying rate under direct solar exposure was consistently higher across all time intervals, with values decreasing over time yet remaining well above those observed in the indirect method. The nearly fourfold increase in mean drying rate further underscores the effectiveness of direct exposure to sunlight in enhancing drying performance.

In a comparative observation, direct sunlight drying removed approximately 75 grams of moisture within just 2 hours, while indirect solar drying extracted only 50 grams over a 10-hour period. This indicates that direct drying is significantly more effective for rapid moisture removal. For carbonization purposes, cassava peels should ideally be dried to a moisture content of 10–12%. Moisture levels above this range require more energy input during carbonization, as excess water must first be driven off before thermal decomposition can proceed efficiently. Conversely, if the moisture content is too low, the biomass may become over-dried, which can accelerate combustion and lead to the formation of excess ash, reducing the yield and quality of the resulting char. Therefore, maintaining an optimal moisture level is essential for energy efficiency and the production of high-quality carbonized material with minimal ash content.

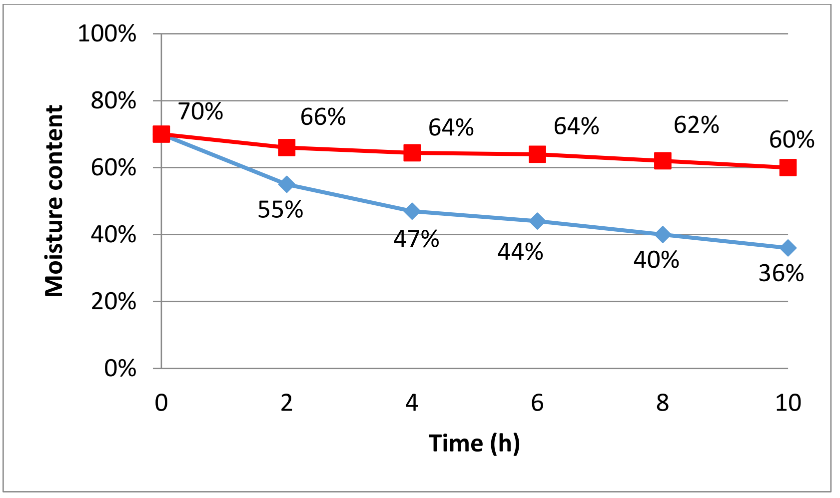

Fig. 3. Characteristics of cassava peel moisture with variations in drying time under direct (red square symbol) and Indirect (blue diamond symbol) solar drying methods

A comparison of moisture content reduction in cassava peels during drying shows a significantly higher drying efficiency in direct sunlight drying compared to indirect solar drying over the same 10-hour period with 2-hour intervals, as illustrated in Figure 3. In direct sunlight drying, the initial moisture content of 70% dropped sharply to 55% in just 2 hours, and continued to decline steadily to 36% by the tenth hour. This indicates rapid moisture removal, likely due to higher solar radiation intensity and better airflow [12], [13]. In contrast, indirect solar drying exhibited a much slower reduction, starting at 70% and reaching only 60% after 10 hours. The decline was minimal in each interval, with only a 10% total moisture reduction. This suggests that while indirect drying may offer more controlled and uniform drying conditions, its efficiency is limited without supplemental heating or improved air circulation. Overall, the data clearly demonstrate that direct sun drying is more effective for rapid moisture removal, which is crucial in pre-carbonization treatments where moisture content must be reduced significantly.

As part of the supplementary observations in this study, cassava peel was stored under open-air conditions to evaluate its natural drying behavior in the absence of controlled solar exposure. Over a period of five days, the sample mass decreased from 500 grams to 180 grams, indicating substantial moisture loss through passive evaporation. This uncontrolled ambient drying process resulted in an extremely dry material, suggesting that natural air-drying could serve as a preliminary step to reduce energy input in subsequent drying or carbonization stages.

However, the final moisture content under these conditions was estimated to be below 10%, which may be suboptimal for effective carbonization. Over-dried biomass can lead to premature thermal degradation, increased ash content, and reduced biochar yield and quality. Moreover, the excessively low moisture content may negatively affect the physical handling and flow properties of the feedstock during processing. Therefore, maintaining an appropriate final moisture content is essential to ensure both energy efficiency and optimal performance during the carbonization process [14], [15].

4 Conclusion

This study presents new findings on the comparative performance of direct and indirect solar drying methods for cassava peel, highlighting significant differences in drying efficiency. Direct solar drying achieved a markedly higher drying rate, nearly four times that of the indirect method, and more effectively reduced moisture content from 70% to 36% within 10 hours. These results indicate that direct exposure to sunlight provides superior drying dynamics, particularly during the early stages of the process, which is critical for biomass pre-treatment.

Supplementary observations from open-air storage revealed that cassava peel naturally dried over five days reached a final weight of 180 grams from an initial 500 grams, suggesting a moisture content below 10%. Although passive drying may reduce energy input, excessively low moisture content can negatively impact carbonization by increasing ash formation and reducing biochar yield. These findings underline the importance of controlling final moisture content to ensure optimal feedstock quality and energy-efficient thermal processing.

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