



Hybrid-Solar-Dryer

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Abstract: Post-harvest agricultural losses in developing regions often reach approximately 30% due to inadequate preservation facilities and the limitations of traditional open-air sun drying. This research presents the design and performance analysis of a hybrid solar dryer developed to provide continuous, high-efficiency drying regardless of weather conditions. The system integrates a flat-plate solar collector with an auxiliary biomass-fuelled gasifier heating unit, utilizing a 50-W photovoltaic panel to power fans for forced convection. Experimental results demonstrate that the hybrid system can achieve stable drying temperatures of up to 80°C with a thermal efficiency of approximately 35%. In performance trials, the dryer successfully reduced the moisture content of highly perishable produce—such as peaches and apples—from initial levels of ~89% to a safe storage level of 15–16% within 2 to 3 days. Furthermore, the integration of solar and biomass energy resulted in a 15% reduction in fuel consumption compared to biomass-only heating. This hybrid technology offers a sustainable, cost-effective, and hygienic solution for agricultural preservation, significantly improving product quality and shelf life in rural and industrial applications.

Keywords: Hybrid Solar Dryer, Biomass Heating, Post-Harvest Loss, Thermal Efficiency, Renewable Energy, Agricultural Preservation, Forced Convection, Moisture Content, Solar Thermal, Sustainable Agriculture, Food Security, Biomass Gasifier, Dehydration Technology, Rural Development.

INTRODUCTION

The preservation of agricultural produce is a critical challenge for global food security, particularly in developing nations where post-harvest losses can reach approximately 30%. Drying is one of the most effective and ancient methods for extending the shelf life of crops by reducing moisture content to a level that inhibits microbial growth and enzymatic reactions. However, traditional open-air sun drying, while cost-free, is fraught with limitations; it exposes produce to environmental contaminants such as dust, insects, and animals, and is entirely dependent on favourable weather conditions. These inconsistencies often result in poor product quality and significant economic losses for farmers.

To address these challenges, solar drying technologies have emerged as a sustainable alternative. While simple solar dryers improve hygiene and drying speed compared to open-air methods, their reliance on intermittent solar radiation remains a significant bottleneck, especially during cloudy days or at night. This intermittency leads to fluctuations in the drying rate, which can compromise the nutritional value and physical appearance of the produce. The integration of auxiliary heating sources has led to the development of hybrid solar dryers, which combine solar energy with biomass, electricity, or thermal energy storage to ensure continuous operation.

LITERATURE REVIEW

These hybrid configurations facilitate continuous operational cycles by utilizing supplemental thermal energy, such as biomass burners or electrical heating elements, to maintain consistent drying temperatures during periods of low irradiance. Beyond mitigating temporal variability, these systems effectively shorten overall processing times and significantly reduce post-harvest losses compared to conventional open-sun drying methods. For instance, Misha et al. demonstrated that integrating an electrical heater into a solar-desiccant system reduced drying time by approximately 24%, while other configurations utilize thermal energy storage to maintain elevated chamber temperatures throughout the night. Furthermore, researchers have experimented with versatile hybrid systems, such as incorporating sawdust burners, kerosene stoves, or liquefied petroleum gas, to ensure the drying process remains independent of climatic fluctuations. These systems frequently incorporate advanced control mechanisms, such as proportional valves or auxiliary heat exchangers, to regulate energy input and maintain precise drying parameters even under adverse weather conditions.

METHODOLOGY

The experimental design process centres on the strategic integration of solar collectors with biomass combustion chambers to optimize thermal output in rural settings. This design methodology prioritizes the selection of solar



collectors at specific tilt angles to align with local climatic conditions, ensuring peak irradiation capture. Concurrently, the biomass burner is engineered to provide a secondary heat source, effectively augmenting the dryer's thermal capacity and ensuring operational continuity during nocturnal hours or periods of high humidity. However, many existing designs lack integrated thermal storage, leading to suboptimal resource management where air temperatures decline to ambient levels shortly after sunset.

RESULTS

Experimental evaluations of hybrid solar-biomass dryers demonstrate notable performance gains. A combined solar-biomass cabinet dryer reached a maximum tray temperature of 53°C with an optimal drying rate of 0.0142 kg/hr for yam chips, surpassing solar-only (0.00732 kg/h) and biomass-only (0.0032 kg/h) modes. Additional tests confirm over 20% efficiency improvement, reducing moisture from 85% to 1% within two hours while sustaining stable temperatures. Hybrid configurations also enable continuous drying independent of sunlight availability.

CONCLUSION

The development and implementation of hybrid solar dryers represent a significant advancement in sustainable agricultural technology, successfully mitigating the limitations of traditional open-air sun drying and standalone solar systems. By integrating auxiliary heat sources such as biomass, electricity, and geothermal energy, these systems ensure continuous operation and process stability.

The following conclusions can be drawn regarding the efficacy of hybrid solar drying:

- **Technical Efficiency:** Hybrid systems exhibit superior thermal performance, with overall efficiencies reaching up to 54% and solar collector efficiencies as high as 81%. They drastically reduce drying durations by 32% to 67%, enabling the processing of high-moisture products like onions and cabbage within 10 to 16 hours.
- **Product Quality:** The transition to controlled hybrid environments preserves up to 90% of the nutritional content and essential oils in agricultural produce. This is further enhanced by AI-driven monitoring, which minimizes thermal degradation and ensures consistent quality.

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