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Research Article

Design and Development of an IoT-Based Sustainable Seaweed Drying: Temperature uniformity (36-40°C) Validation for "*Kappaphycus alvarezii*"

Rey Christian M. Villarin[1], Leah A. Alindayo, D'Eng[2], Stefany Mae V. Caparida, MSCA[3], Maria Fe P. Bahinting, MIT[4], Cherry Mae J. Galangque, D'Eng[5]

[1]*MSCA Student, Department of Computer Applications, Mindanao State University – Iligan Institute of Technology, Iligan City, Philippines.*
[2]*Asst. Prof., Department of Computer Applications, Mindanao State University – Iligan Institute of Technology, Iligan City, Philippines.*
[3]*Asst. Prof., Department of Computer Applications, Mindanao State University – Iligan Institute of Technology, Iligan City, Philippines.*
[4]*Asst. Prof., Department of Computer Applications, Mindanao State University – Iligan Institute of Technology, Iligan City, Philippines.*
[5]*Assoc. Prof., Department of Computer Engineering and Mechatronics, Mindanao State University – Iligan Institute of Technology, Iligan City, Philippines.*

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ABSTRACT

Introduction: Seaweed farming is a primary livelihood in coastal areas of the Philippines, especially in Tawi-Tawi, where *Kappaphycus alvarezii* is widely used for carrageenan production. However, traditional sun drying methods, though affordable and straightforward, are inefficient, requiring 5–7 days and exposing seaweed to contamination, inconsistent quality, and income loss for farmers. To address these challenges, the proposed system integrates IoT sensors, renewable energy, and a web-based dashboard to improve drying efficiency and temperature stability. System performance was validated through thermal simulations and real-time testing.

Objectives: The study aims to develop a more efficient and sustainable seaweed-drying system that preserves product quality, shortens drying time, and operates using renewable solar energy. It focuses on designing and validating an IoT-based hybrid dryer that maintains a stable drying temperature, integrates intelligent monitoring with web-based and SMS control, and provides a scalable solution for coastal farming communities. The project supports improved post-harvest processing, enhanced carrageenan quality, and aligns with the UN Sustainable Development Goals.

Methods: The study employed an experimental approach to develop and evaluate an IoT-based hybrid seaweed dryer integrating solar energy, intelligent monitoring, and automated control. An off-grid solar system powered the central controller, sensors, PTC heating element, and exhaust fan, regulating temperature, humidity, and moisture in real time. Drying data were continuously recorded and statistically analyzed to assess drying efficiency, moisture reduction, product quality, and energy consumption relative to traditional methods. A hysteresis-based control algorithm maintained the temperature within 36–40 °C by automatically managing heater and fan operation. Data were logged every 15 minutes to a web-based database for monitoring and analysis.

Results: The IoT-based hybrid dryer prototype successfully integrated an off-grid solar power system, web-based monitoring, and automated control, enabling continuous, sustainable operation. The drying chamber design ensured efficient heat and airflow distribution, validated through simulation and experimental testing. Results showed stable temperature control within the optimal 36–40 °C range, maintaining thermal uniformity within ±2 °C across multiple trials. Real-time IoT monitoring, web-based control, and SMS notifications enabled remote supervision and automated adjustments. The system demonstrated effective humidity reduction, consistent drying performance, and reliability under varying environmental conditions, confirming its suitability for sustainable seaweed post-harvest processing.

Conclusions: This study successfully addressed the limitations of traditional seaweed drying by developing and validating an IoT-based hybrid dryer powered by renewable solar energy. The system achieved stable temperature control within the optimal 36–40 °C range using automated sensor-based monitoring, web-based control, and SMS notifications. Experimental results and simulation testing confirmed uniform heat distribution, effective moisture reduction, and reliable performance under varying environmental conditions. The integration of intelligent control and sustainable energy enhances drying efficiency, product quality, and post-harvest processing, offering a practical and scalable solution for seaweed farmers, particularly in remote coastal communities.

Keywords: Seaweed farming, Internet of Things, hybrid solar dryer, solar energy, post-harvest processing, temperature stability, drying efficiency

INTRODUCTION

Seaweed farming is a significant economic activity in the coastal communities of the Philippines, particularly in Tawi-Tawi, where *Kappaphycus alvarezii* is the primary species used for carrageenan extraction, a method widely employed in the food, cosmetics, and pharmaceutical industries [1]. Seaweeds are valuable resources that are perishable and susceptible to spoilage during post-harvest handling due to their high moisture content and tendency of sand and other impurities to be mixed with the seaweeds if dried on the ground [2]. Drying is a crucial step in the seaweed processing chain as it reduces moisture content and increases the shelf life of seaweed products. Traditional drying methods such as sun drying, and open-air drying are still the most common ways used by seaweed farmers in Tawi-Tawi. These drying methods are widely used due to their low cost and simplicity. However, these traditional drying methods have several limitations, including long drying times, inconsistent drying quality, energy inefficiency, and vulnerability [3]. Addressing post-harvest handling issues is crucial for the efficient management of seaweeds. It discussed the importance of proper post-harvest practices in maintaining the quality and quantity of carrageenan derived from seaweed biomass [4].

Traditional drying methods, primarily sun drying, are inefficient, requiring 5 to 7 days under ideal conditions [5]. These methods expose seaweed to contaminants and degrade quality, resulting in lower market prices and impacting farmers' income stability [6]. The traditional sun-drying process of seaweed involves gradual moisture loss over several days. Initially vibrant and densely packed, the seaweed undergoes visible changes as it shrinks and darkens, reflecting moisture reduction. By the end of the drying period, the seaweed appears fully dehydrated, with a lighter color and reduced volume. These limitations underscore the need for a more efficient and controlled drying method, such as the traditional sun drying method, to ensure quality and reduce drying time, an example of which is shown in Figure 1.

Figure 1. Traditional sun-drying method

The proposed system aims to improve drying efficiency, ensure temperature equilibrium, and reduce reliance on manual monitoring by leveraging IoT sensors, renewable energy, and a web-based dashboard. Performance testing helps to validate the temperature equilibrium of the hardware using sensors and actuators [7]. The system was tested and validated through both thermal simulations and real-time experimental observations to assess temperature stability, humidity control, and overall drying performance [8].

OBJECTIVES

The general objective of this study underscores the need for a more efficient and sustainable seaweed-drying method that preserves product quality, minimizes drying time, and supports continuous operation via a renewable solar energy system. Addressing this gap, the research successfully advances its objective of optimizing the drying process while ensuring product quality and sustainability by designing, developing, and validating an IoT-based hybrid seaweed dryer that maintains a stable temperature range of 36–40 °C. The system's integration of intelligent monitoring and solar-powered operation provides a practical and scalable solution tailored for coastal farming communities. Ultimately, the innovation enhances carrageenan quality, strengthens post-harvest processes, and supports the long-term resilience and productivity of *Kappaphycus alvarezii* growers. Through this experimental study on the design and development of sustainable drying, the drying process can be improved by utilizing the Internet of Things, web-based application monitoring and control management, and SMS notification systems [9][10]. The research aligns with the United Nations Sustainable Development Goals (SDGs), specifically Goal 9: Industry, Innovation, and Infrastructure Goal 12: Responsible Consumption and Production Goal 13: Climate Action [11].

REVIEW OF RELATED LITERATURE

These recent advancements in sustainable seaweed preservation and intelligent drying technologies emphasize how solar, hybrid, and IoT-enhanced systems significantly improve drying efficiency and product quality. By integrating automation, real-time monitoring, and energy-optimized designs, these studies demonstrate the growing potential of innovative drying systems in agricultural applications. Together, these works provide a strong foundation for developing an innovative hybrid dryer tailored for *Kappaphycus alvarezii* and aligned with sustainable, technology-driven practices.

A. Sustainable Seaweed Preservation

In sustainable seaweed preservation through technological advancements in drying processes. They demonstrated the effectiveness of a solar dryer equipped with a fuzzy logic controller in significantly reducing drying time and improving the quality of *K. alvarezii*, a commercially important seaweed [12]. This finding aligns with the broader potential of IoT-based smart solar dryers [13], which can optimize drying parameters, reduce energy consumption, and enhance product quality in agricultural settings. Further emphasizes the transformative role of IoT in agriculture, highlighting its applications in data-driven decision-making and automation, thus reinforcing the significance of integrating technology into seaweed drying for enhanced efficiency, sustainability, and product quality [14].

B. Integration of IoT-Based Solar Energy Dryer

Developed an IoT-based solar energy dryer that enhances agricultural drying processes through real-time monitoring and control of temperature, humidity, and airflow. The system significantly improved drying efficiency, energy optimization, and product quality while allowing remote management via a mobile application. By leveraging solar energy, the dryer reduced operational costs and environmental impact, making it a sustainable solution for small-scale and large-scale applications. Despite challenges like high initial costs and internet dependency, the study demonstrated the system's scalability and potential for widespread adoption in agricultural practices.[15]

C. Optimizing Drying Efficiency Through an IoT-based Direct Solar Dryer System: Integration of Web Data Logger and SMS Notification

Developed an IoT-based direct solar dryer system that integrates a web data logger and SMS notifications to optimize drying efficiency. The system enables real-time monitoring of temperature, humidity, and drying duration through IoT sensors, allowing for remote management and automation. This approach reduced drying inconsistencies, minimized energy waste, and enhanced product quality by maintaining a controlled environment [16].

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D. A Novel Design of Hybrid Solar Dryer for Drying Agricultural Products

[14] In this study, proposed a novel design for a hybrid solar dryer that combines solar energy with biomass heating. The system includes a solar collector, a drying chamber, and a biomass furnace. The researchers evaluated the performance of the hybrid dryer in drying various agricultural products and found that it achieved higher drying rates and energy efficiency compared to conventional solar dryers. This research supports the current study's exploration of hybrid solar drying technology as a means to overcome the limitations of traditional solar dryers.

METHODS

A. System Architecture Development Process

This study is primarily designed for experimental purposes by integrating advanced IoT technology, efficient energy management, and precise control mechanisms. This alignment ensures the development of a sustainable, efficient, and hybrid dryer for seaweed, reinforcing the theoretical foundations and practical goals of the research. It features an off-grid solar setup for energy management, a main board for coordinating sensor data collection, and various sensors and actuators to monitor and control drying conditions, especially the temperature. See Figure 2. System Architecture.

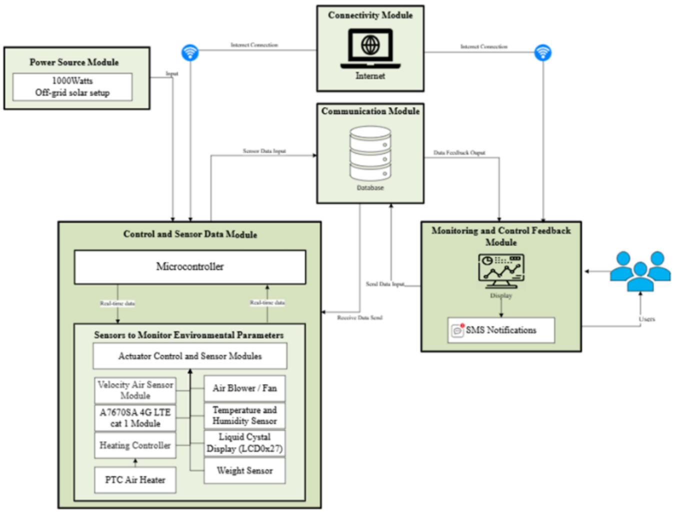

Figure 2. System Architecture

The IoT-based hybrid dryer comprises solar panels for sustainable energy, a PTC heating element for maintaining consistent heat, and an exhaust fan to regulate airflow. IoT sensors monitor key parameters, such as temperature, humidity, and moisture, in real-time, enabling precise control over the drying environment. The drying chamber optimizes air circulation, and data from sensors are processed by a microcontroller, which adjusts heating and ventilation systems to maintain optimal drying conditions.

B. Data Collection and Analysis

Data on temperature, humidity, and moisture levels are recorded throughout the drying process. Statistical analysis will be conducted to evaluate the drying efficiency, product quality, and energy consumption of this method compared to traditional methods. The effectiveness of the dryer will be assessed based on drying time, moisture reduction rate, and the quality of the dried product. Figure 3 shows the overall system structure of this study.

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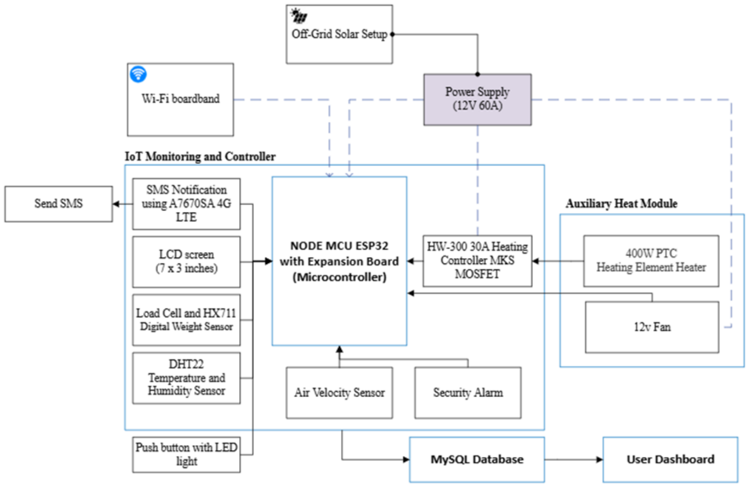

Figure 3. Overall System Structure

C. Control Algorithm Design

The hysteresis-based control algorithm was designed to manage fan and heater operation based on real-time sensor feedback. When the chamber temperature drops below 36 °C, the PTC heater activates until it reaches the upper threshold of 40 °C, after which the exhaust fans regulate airflow to maintain equilibrium. The algorithm minimizes 150scillations and energy wastage, promoting stable heat distribution.

A simplified pseudocode representation:

If Temp < 36°C → Heater ON, Fan Low

If Temp > 40°C → Heater OFF, Fan High

If 36°C ≤ Temp ≤ 40°C → Maintain previous state

The control system is implemented using C++ in the Arduino IDE 2.3.3 environment. Data are logged every 15 minutes to a MySQL database hosted on a XAMPP server via HTTP POST requests.

RESULTS

A. Prototype Design of the Hybrid Dryer

Designed a prototype of the IoT-based hybrid dryer, integrating an off-grid solar system, web-based application, and control features. The off-grid solar system powers the PTC heating element, exhaust fan, and IoT sensors, enabling continuous operation without reliance on external power sources.

The web application provides real-time monitoring and control, accessible via mobile and desktop devices. Users can view temperature, humidity, and moisture data and adjust settings remotely to maintain optimal drying conditions. This capability enables users to monitor the drying of seaweed even when they are not physically present at the dryer site. It was embedded in the dryer.

The drying model design of the IoT-based hybrid dryer used in the study and to evaluate temperature and airflow distribution. The chamber model measured 160×100×60 cm with single tray of seaweed samples. The structure features a transparent curved top for sunlight exposure, an insulated drying chamber, and multiple trays for drying seaweed. The design includes an exhaust fan and air vents to enhance airflow. The dimensions and layout are optimized to support effective heat distribution and efficient drying, which is crucial for achieving consistent moisture reduction during the drying process.

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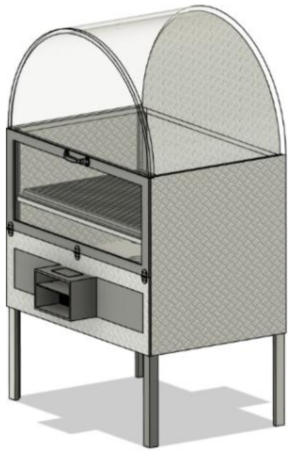

Figure 4. Dryer Model Technology of Drying Chamber

B. Renewable off-grid solar setup design and components

The 12V off-grid solar setup is part of the IoT-based hybrid dryer designed for seaweed drying. This system ensures the continuous operation of the drying process by harnessing renewable solar energy, which is particularly advantageous for remote coastal areas with limited access to electricity. The setup comprises several key components, each serving a specific purpose to boost energy efficiency and system reliability. This renewable energy system was integrated into the prototype of the hybrid dryer to enable the drying devices.

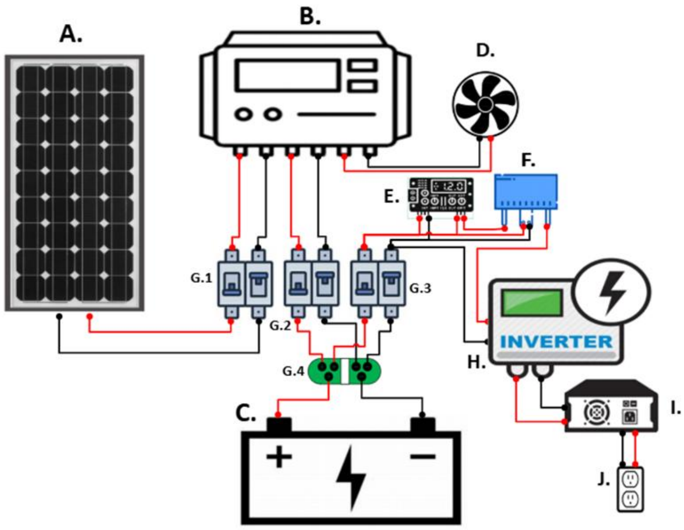

Figure 5. Off-Grid System Components

1) Energy efficiency and sustainability

This off-grid solar setup supports the Sustainable Development Goals by reducing reliance on fossil fuels and lowering its carbon footprint. Adding an MPPT solar charger controller greatly enhances energy efficiency by optimizing the voltage and current from the solar panel. The battery storage system enables continuous drying operations, helping to mitigate the effects of adverse weather conditions.

2) Role in the hybrid dryer

The off-grid solar system powers part of the hybrid dryer, including:

- The PTC heating element: Provides consistent heat for drying seaweed.
- Exhaust fans and airflow control systems: Maintain proper air circulation to enhance moisture removal and

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improve indoor air quality.

- IoT-based monitoring and control system: Allows real-time tracking of temperature, humidity, and drying status via a web-based application.

This design ensures that the drying process is both energy-efficient and cost-effective, making it an ideal solution for small-scale seaweed farmers in remote areas.

C. IoT device system design and components

This study develops IoT devices that monitor multiple temperature points and a humidity sensor to maintain the chamber within the optimal 36–40 °C. A load cell with X711 monitors the seaweed's weight, allowing us to track moisture loss in real time. Airflow is tracked, while a PTC heater and two DC fans handle gentle, efficient warming and circulation through PWM and protected driver stages. A simple I²C LCD shows on-site status, and Wi-Fi/SMS pushes alerts and logs to a local MySQL database for later analysis. Because it can run from solar and guards the battery with low-voltage protection, the setup supports sustainable operation. Overall, it's a practical, data-driven platform for simulating and testing our hybrid dryer, which is shown in Figure 6.

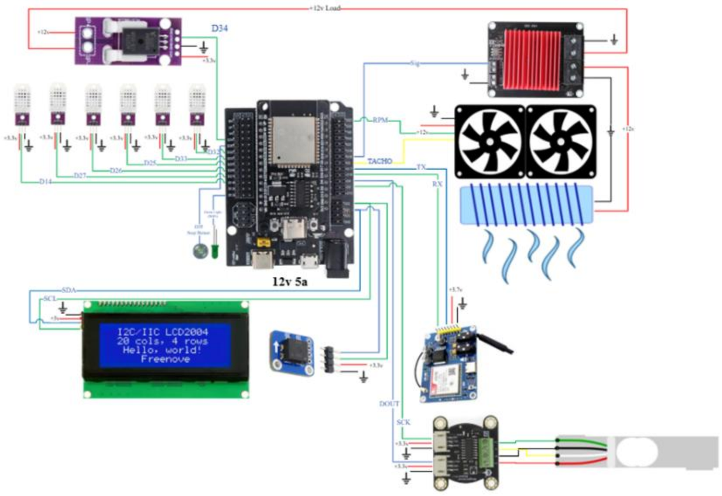

Figure 6. IoT Devices and Circuit Diagram

D. Simulation testing and performance

A simulation was conducted to analyze airflow and temperature distribution throughout the drying chamber. Results showed stable airflow and a uniform temperature gradient, indicating that the dryer maintains optimal drying conditions.

The simulated data demonstrated that the heated air evenly reaches all trays, which is critical for consistent moisture reduction across different layers of seaweed. This result validates the design of the drying chamber, showing that the hybrid dryer can achieve efficient drying even with stacked trays. Used the simulation insights to refine the prototype, particularly in applying exhaust vents and airflow regulation.

The thermal simulation of the IoT-based hybrid seaweed dryer, conducted at 105 iterations, revealed a temperature range of 20.5°C to 40.05°C, confirming effective heat distribution. Higher temperatures at the bottom indicate efficient heating. The system achieved an equilibrium variation of only ±2 °C, indicating excellent thermal consistency. Integrating IoT devices for real-time monitoring and automated fan control can help neutralize temperature imbalances, ensuring consistent drying efficiency while preventing overheating and uneven moisture removal. See Figure 7.

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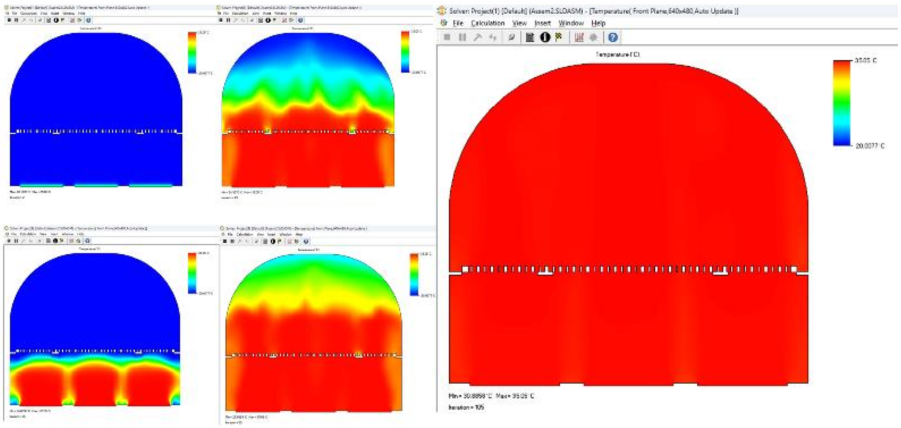
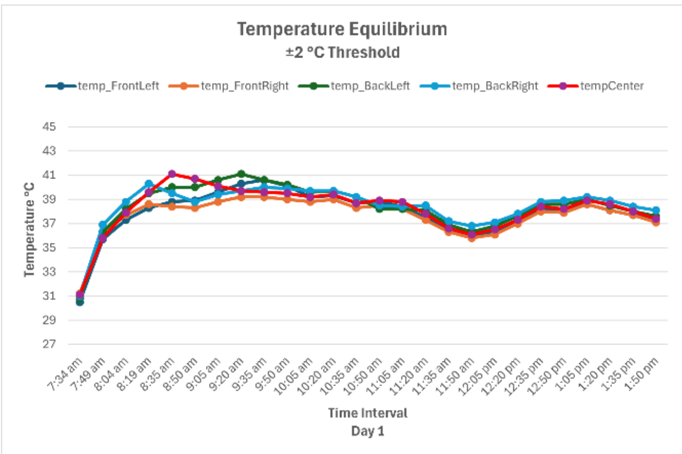


Figure 7. Thermal Distribution Plot

E. Performance testing of temperature analysis and observations

In Figure 8, the researcher aimed to maintain the dryer temperature between 36–40 °C, checking temperatures every 15 minutes and using a ±2 °C spread as the uniformity yardstick. The chamber warmed from ambient to a steady range and, for most of the run, held predominantly within the 36–40 °C band. Two brief departures stood out: an early overshoot reaching about 41 °C, and a coordinated cooling dip to roughly 36.5–37.0 °C. After the dip, the system recovered to around 38.5–39.8 °C, then eased toward ~37.5–38.2 °C near the end. Spatial differences were minor—one area tended slightly warmer during the peak, another marginally cooler during the dip. Overall, most observations met the ±2 °C uniformity criterion, indicating stable, near-isothermal conditions consistent with the intended drying regime.



Figiure 8. Day 1 Plot

In Figure 9 kept the 15-minute checks, the ±2 °C uniformity yardstick, and the 36–40 °C target. The dryer warmed quickly from ambient temperature, briefly overshooting to about 42–43 °C, then settled close to the target. Most of the time, all sensors moved together within the ±2 °C window, indicating even heating. The standout event was a deeper, system-wide cool-down than Day 1, dipping to roughly 33–35 °C before climbing back into the high 30s toward the finish. Because every trace dropped in unison, this appears to be a whole-system disturbance (e.g., a short loss of heat input or a door opening) rather than an air-flow problem. A slight spatial bias remained; one back area ran a touch warmer during the peak, while the opposite side was a bit cooler during the dip, but these differences were slight and brief. Overall, Day 2 exhibited mostly near-isothermal performance, with short excursions below the 36–40 °C range. It's worth reviewing the heater duty logs and airflow/baffle settings to pinpoint the cause of the dip.

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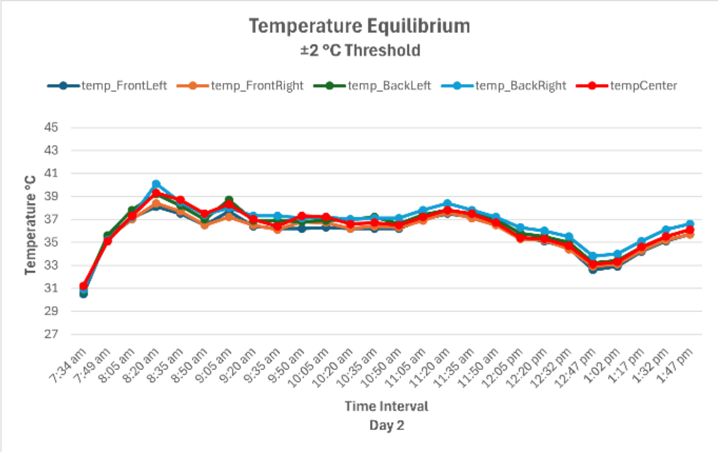

Figure 9. Day 2 Plot

In Figure 10 with rain and cooler ambient air as the backdrop, the researcher kept the 15-minute checks, the ±2 °C uniformity yardstick, and the 36–40 °C target. The dryer warmed quickly from ambient, showed a brief, modest overshoot near ~42 °C, and then settled cleanly into the control band. What stands out is how closely the traces moved together: the five sensors clustered tightly for almost the entire run, with only small, short-lived ripples around the upper 30s. There was no deep, system-wide dip below the target band despite the wet weather, and end-segment temperatures held in the high 30s with minimal spread. In plain terms, the system kept a steady, even heat profile throughout the rainy-day trial.

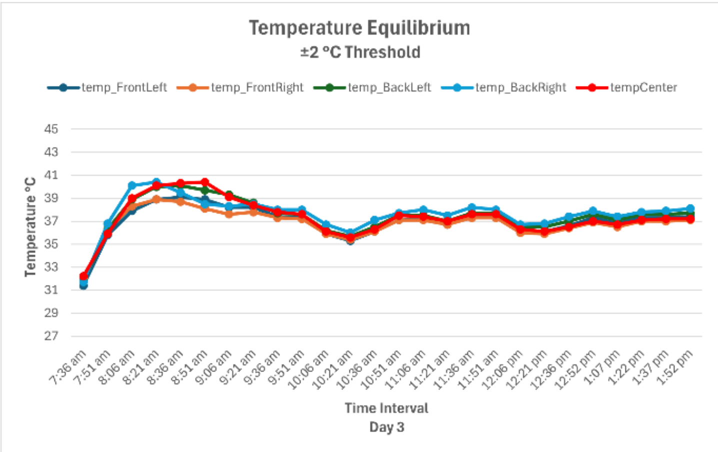

Figure 10. Day 3 Plot

In Figure 11 shows the cleanest thermal behavior across the series: a rapid rise into the 36–40 °C target followed by a long, flat plateau where all sensors track almost identically, with only tiny ripples and a spread typically within about 2 °C. Unlike Figure 8, which met the target for most of the run but showed a brief early overshoot and a mid-session dip, and Figure 9, which clustered well yet experienced the deepest cool-down into the low to mid-30s before recovering, Figure 10 maintains steady, near-isothermal conditions throughout. Compared with Figure 10, which already shows a strong performance despite rainy, cooler ambient air and only a slight early overshot, day 4 still edges ahead by delivering the tightest clustering and the highest fraction of time squarely within the control band. In short, Figure 11 provides the most suitable result among days 1–3.

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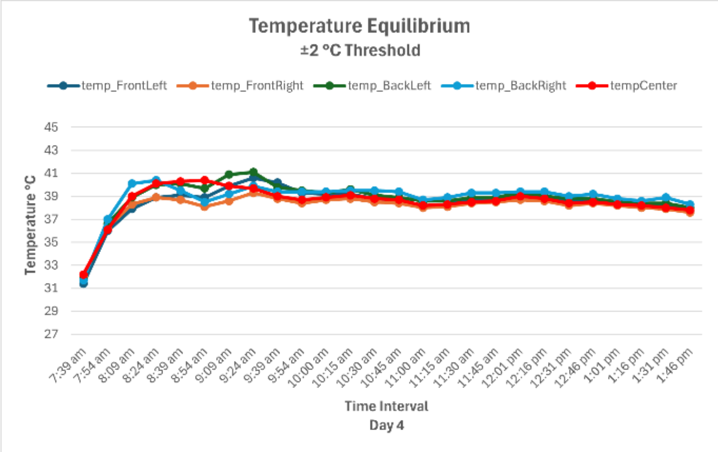

Figure 11. Day 4 Plot

In Figure 12 shows a clean temperature–humidity story at the chamber center. Temperature climbs from 32–33 °C to the target band (36–40 °C) during warm-up, then holds steady in the high-30s with only small ripples—consistent with the uniform, near-isothermal behavior seen in your multi-probe plot. Relative humidity initially decreases inversely, from 70% to 50%, as the air warms and its moisture-holding capacity increases. After stabilization, humidity hovers mostly around 50–53% with gentle oscillations (a brief dip to 48% and later increases to 54–55%). Meanwhile, the temperature remains stable. This pattern, characterized by an early RH drop during heat-up followed by mid-band fluctuations around 50%, is typical of active drying: the air is warm enough to carry moisture away, RH is moderate, and neither variable exhibit disruptive swings. In short, Figure 11 sustains the 36–40 °C regime with mid-range RH, indicating a consistent, drying-favorable environment.

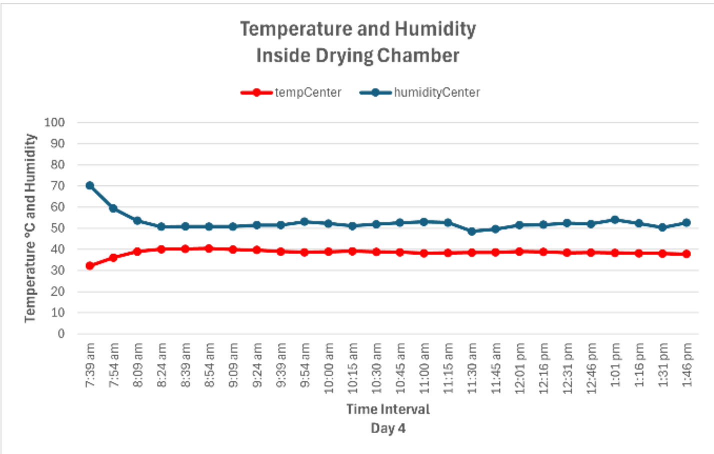

Figure 12. Temperature and Humidity Inside Drying Chamber Plot

In Figure 13 ambient conditions show a gentle temperature climb from roughly 28–30 °C toward 32–34 °C, then a mostly flat profile in the low-to-mid 30s for the remainder of the test. Relative humidity begins high—around the mid-70s to low-80s then steadily eases to the mid-60s, with a distinct dip to about 56–58% before rebounding and mainly hovering in the 60–65% range. This pattern—slightly warming air paired with a net RH decrease and a midday trough indicates improving ambient drying potential as the session progresses. When read alongside the chamber-center plot for Figure 11, the key takeaway is that the internal temperature remained stable within the 36–40 °C regime despite these ambient swings. In contrast, the ambient RH drop would have supported moisture removal without imposing a cooling penalty on the chamber.

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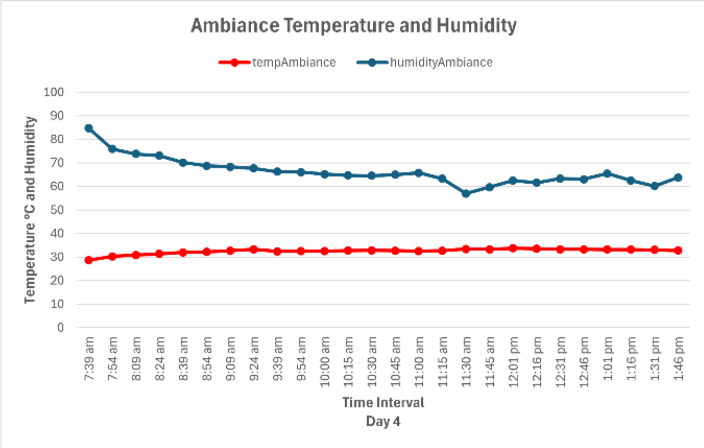

Figure 13. Ambiance Temperature and Humidity Plot

The drying performance results, as shown in the figure, present the temperature and humidity dynamics inside the IoT-based hybrid drying chamber for *Kappaphycus alvarezii*. The temperature readings from 6 DHT sensors see Figure 6 (temp_FrontLeft, temp_FrontRight, temp_BackLeft, temp_BackRight, tempCenter, humCenter, tempAbiance, humidityAmbiance) demonstrated a consistent and gradual rise, stabilizing within a controlled range from 36°C to 40°C, as per the designed thermal limit, see Figure 7. This upper limit aligns with optimal drying conditions for seaweed products.

Importantly, temperatures across all internal nodes remained within the ±2°C equilibrium threshold, affirming uniform heat distribution —a critical parameter for product consistency, as emphasized [28]. The convergence of the sensor readings toward thermal stability supports the system's effectiveness in mitigating heat gradient variations across the chamber.

The ambient temperature, which remained significantly lower than the chamber interior, confirms that the system's enclosure and insulation effectively contained and maintained internal heat. This isolation is essential for consistent drying performance regardless of external environmental fluctuations.

The feedback loop based on DHT22 successfully regulated the temperature using a hysteresis-based control strategy, maintaining chamber conditions within the desired range. As recommended, a 15–30-minute data acquisition interval was applied, proving sufficient to capture critical thermal transitions without excessive noise or processing overhead.

Initially, the performance affirms that the drying chamber achieved controlled internal temperatures up to 40 °C, maintained thermal equilibrium within ±2 °C, and enabled steady humidity reduction. These conditions are conducive to efficient and uniform drying, supporting the system's suitability for seaweed post-harvest processing. The integration of IoT for real-time sensing and control further enhances its relevance as an innovative, scalable, and sustainable solution for agricultural drying.

Table 1. Temperature stability across experimental trials inside the drying chamber

Day	Temperature Range (°C)	Average Humidity (%)	Uniformity (±°C)	Remarks
1	36–41	53	±2.1	Slight overshoot at start
2	33–40	55	±2.5	Drop due to power fluctuation

3	37–39	51	±2	Stable during rainy conditions
4	36–38	50	±2	Most stable performance

Note: 4 days of consecutive experimental system hardware and software testing.

F. Web Application Monitoring Design

The IoT-based hybrid dryer enhanced drying efficiency through a web-based application that provided real-time monitoring and control of drying conditions. The web application provided users with continuous access to essential drying parameters—temperature, humidity, and moisture levels—through web interfaces. This capability allowed users to remotely monitor and adjust drying settings, ensuring optimal conditions throughout the drying process.

The real-time monitoring feature enabled the dryer to maintain stable drying conditions, thereby reducing its dependency on external factors, such as weather. By automatically adjusting the temperature, fan speed, and other settings based on sensor feedback, the system minimized the need for manual interventions, which are often required in traditional drying methods. This automation and remote accessibility allowed consistent drying.

The web application's monitoring and adjustment capabilities represent a significant advancement in drying efficiency for seaweed processing. By providing users with real-time data and remote-control options, such as a start and stop drying button, the system ensures that drying continues uninterrupted and efficiently, regardless of environmental conditions. This IoT-driven web application monitoring approach not only optimizes energy use but also aligns with sustainable practices, supporting efficient and consistent seaweed drying monitoring systems.

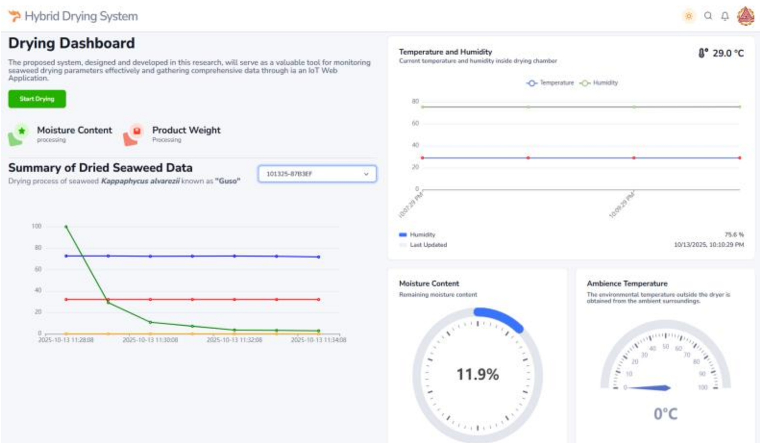

Figure 14. Drying Dashboard

G. SMS Drying monitoring and notification system

An SMS drying monitoring and notification system collects sensor or status data, evaluates simple rules (e.g., setpoints, threshold crossings, ambiance, temperature, and humidity) through sensors, and dispatches alerts over cellular networks either via an A7670SA 4G module or a SIM-based system, as seen in Figure 6. This setup makes it resilient in areas with weak internet links and where delivery confirmation is essential. The integration of HTTP calls in the ESP32 microcontroller is part of the experimental study. This feature enables users to monitor and receive notifications during the drying process, as illustrated in the figure below.

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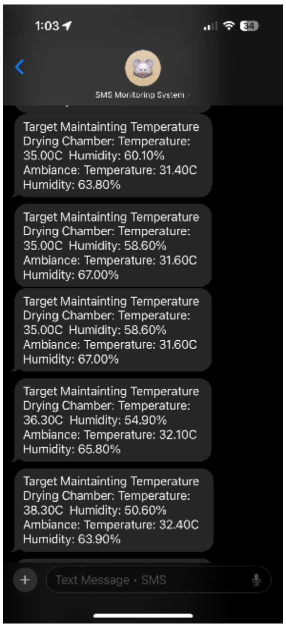

Figure 15. Short Message Services (SMS) Notification

DISCUSSION

The results validate the feasibility of integrating IoT automation with hybrid renewable systems for post-harvest seaweed processing. The achieved temperature uniformity (±2 °C) indicates high thermal reliability, essential for maintaining seaweed quality. This uniform drying environment ensures consistency in product moisture content and prevents localized overheating.

From a control perspective, hysteresis regulation successfully maintained stability with minimal computation, ideal for low-cost microcontrollers. Hysteresis-based control reduces delay and simplifies implementation without significant energy penalties. The observed energy savings and consistent temperature levels underscore the potential of this method for small-scale, off-grid applications.

The IoT-enabled monitoring system enhanced operational transparency. Real-time data visualization through a web dashboard allowed users to observe drying conditions remotely. The inclusion of SMS notifications ensured redundancy in low-connectivity areas, offering alerts for deviations or completion states. This capability directly supports smallholder farmers in remote coastal communities, enabling responsive and data-driven post-harvest management.

The study's integration of renewable energy contributes to the broader sustainability discourse. Solar-based power reduces carbon emissions and aligns with the Philippine government's push toward green technologies for aquaculture and agriculture. The proposed dryer supports the circular economy framework by minimizing energy waste and maximizing resource efficiency.

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