

Smart Solar Dome Dryer: IoT-Integrated Automatic Hybrid Drying System for Cereal Grains

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ABSTRACT

The drying process for cereals is essential to reduce the moisture content of grains to an optimal level of 12%; however, it is often hindered by the unpredictable tropical climate. This study aimed, firstly, to design a solar dome dryer for drying grains using solar energy and, secondly, to develop an automatic control system for a hybrid solar-heated system based on the Internet of Things (IoT). The research started with engineering design, followed by drying test using single-factor of different grains. The Solar Dome Dryer (SDD) was constructed with a lightweight steel frame covered by UV-resistant plastic, sizing 2 × 1 m and with a capacity of 25 kg. It is equipped with an exhaust and heater operating in a hybrid mode during day and night, controlled by DHT22, BH1750, and capacitive soil moisture sensors integrated with a Smart SDD application on a smartphone. Results showed that percentage error, MAE, RMSE, and R² values were below 1%, indicating high sensor accuracy and consistency. The final moisture contents of 12% were achieved in the following grains: rice 4.72 h, red rice 6.20 h, glutinous rice 6.20 h, black glutinous rice 6.62 h, feed maize 7.35 h, sweet maize 7.62 h, glutinous maize 7.27 h, white sorghum 6.20 h, brown sorghum 5.99 h, and red sorghum 5.64 h. ANOVA of drying using SDD was faster than conventional, even while performing drying during rainy conditions.

1. INTRODUCTION

Grains is a term used to refer to the cereal group, a type of plant that is a staple food worldwide. The types of grains commonly found and cultivated in Indonesia are rice (*Oryza sativa*), corn (*Zea mays*), and sorghum (*Sorghum bicolor*) (Andriyono *et al.*, 2023). Based on data from the Ministry of Agriculture, rice production reaches 54.42 million tons, corn 21.6 million tons, and sorghum around 100,000 tons (Kementan, 2024). The cultivation potential of each crop contributes to the supply of staple foods for the Indonesian people.

Post-harvest processing includes threshing, cleaning, drying, sorting, grading, storage, transportation, distribution, and further processing (Faris *et al.*, 2020). The biggest challenge is the drying process, as high moisture content can cause losses of up to 20% if not managed properly. High moisture content can lead to mold growth, self-heating, germination, and pest infestation (Amuddin *et al.*, 2025).

The drying process reduces the moisture content of a material to inhibit microbial growth and enzyme activity. The wet moisture content of rice is 20–25%, corn 18–24%, and sorghum 18–22%, while the ideal moisture content for storage is 12–14% (Soekarno *et al.*, 2024). Indonesia's tropical climate makes direct sunlight drying a long time, taking 4–7 days. Unpredictable sunlight intensity, especially during the rainy season, hinders the drying process, resulting in rapid microbial growth and enzyme activity (Nguyen *et al.*, 2023). Conventional drying is only performed

at 15–30 °C, while the optimal temperature is 40–50 °C. Temperatures above 50° C can cause cracking in the beans, reducing the quality of the drying process (Chang *et al.*, 2024).

Long drying times increase operational costs in production, necessitating appropriate technology to rapidly reduce moisture content (Mariyam *et al.*, 2021). Numerous and varied drying methods have been developed, ranging from simple to sophisticated and expensive. A solar dome dryer uses ultraviolet light to manipulate the required microclimate (Setiawan *et al.*, 2022). A solar dome dryer consists of UV plastic, racks, solar panels, storage, an inverter, exhaust, a heater, and several other accessories. Solar dome dryers can be combined in a hybrid way, using solar energy during the day and biomass energy or electric heating at night (Cenggoro *et al.*, 2022). Hybrid drying systems require technology for automatic control to reduce drying times. Automatic control is a component of precision agriculture and can also be combined with the internet of things (IoT) for real-time monitoring to ensure the hybrid system operates automatically between solar energy and heating (Insan & Witanti, 2024). Monitoring the drying process can be done using temperature and humidity sensors, water content sensors, and sunlight intensity sensors on solar dome dryers (Gunawan *et al.*, 2022). IoT allows users (farmers) to determine the day when the product is dry and ready for the next stage of production. However, IoT technology still requires additional information to predict drying time based on water content parameters (Hasibuan *et al.*, 2021).

Previous research on solar dome dryers has been applied to drying vegetables (Hossain *et al.*, 2025), watermelons (Soekarno *et al.*, 2024), and crops (Viviane *et al.*, 2023) by utilizing microclimates (Kurniawan *et al.*, 2021; Daliran *et al.*, 2023). While previously unhygienic rice drying methods were not yet implemented, they can be implemented based on the Internet of Things (Andriyono *et al.*, 2023; Insan & Witanti, 2024). However, solar dome dryers for corn and sorghum have previously only used other drying methods (Tanggasari & Jatnika, 2023; Mariyam *et al.*, 2021; Ma'arij & Yudhana, 2023).

Utilization of the internet of things uses sensors to monitor air temperature and humidity, sunlight intensity, and water content (Lestari *et al.*, 2024; Putri *et al.*, 2023). The novelty of the solar dryer system is combined with hybrid drying to optimize time and efficiency during rainy days, which can be monitored using a smartphone (Peralta-Jaramillo *et al.*, 2022; Budiman *et al.*, 2022; Rajmane *et al.*, 2023; Venica *et al.*, 2024; Ayeni & Adesoba, 2025). The purpose of this research is first, to design a solar dome dryer for drying grains using solar energy. Second, designing automatic control on a hybrid solar energy and heating system based on the internet of things (IoT).

2. MATERIALS AND METHODS

2.1. Time and Location

The research was conducted at the Sri Rahayu II Rice Mill, Jl. Koperades, Hamlet II Kalikidang, Kalikidang, Sokaraja District, Banyumas Regency, Central Java 53181. Sansiro Rice Mill, Kalikidang Village, Sokaraja District, Banyumas Regency, coordinates 7°28'8" S 109°16'16" E. The research period was from July 20, 2025, to September 20, 2025.

2.2. Materials and Equipment

The materials used were 50 kg of each material. For the trial, 25 kg were used, while for data collection, 25 kg were used. The research materials used were unhusked rice, red rice, glutinous rice, black glutinous rice, feed corn, sweet corn, glutinous corn, red sorghum, white sorghum, and brown sorghum. The tools are divided into hardware, software, measurement and supporting equipment as can be seen in Table 1. The research was executed in steps, as presented in Figure 1.

2.3. System Design

a. Solar Dryer Dome

The solar dryer dome design measures 2 m × 1 m, with a 60 cm leg height and an overall height of 120 cm. The main components consist of a UV plastic cover, four metal plate storage racks, and lightweight steel legs. The automatic control system, exhaust, and heater are powered by solar energy.

Tabel 1. Research equipment

Solar Dome Material & Tools	Electronics Control System	Solar-Powered	Software	Measurement Tools	Supporting Equipment
Lightweight steel	DHT22 Sensor	Solar Panel 400WP	Google Firebase	Thermo-Hygrometer	Rivet Tools
Lightweight steel battens	BH1750 Sensor	Solar Charge Controller	Google Collaboratory	Lux Meter	Cordless Drill
Hollow steel section	Capacitive Soil Moisture Sensor	Battery LiFePO4 12v 120Ah	Arduino IDE	Grain Moisture LDS-1S	Grinder
Self-drilling screw	Load Cell 200 Kg Sensor	BMS	Android Studio	Grain Moisture Kuber AR991	Tin Snips
Rivets	ESP32 Microcontroller	Inverter DC to AC 1.000 W		Digital weighing scale	Clamp Pliers
Hinges	LCD I2C 20x4	Dimmer 2000 W			Electrodes (for welding)
UV Plastic Sheet	Relay 2 Channel	Cable			Adhesive (glue)
Door Handle	ESP32 Cam	Power Strip 4 Socket			Screwdriver
Exhaust Fan 56 W 220V	Resistor				Grinding disc
Heater AC 100 W	USB Cable Box Controller Switch On/Off PCB Jumper Wires				Material Container

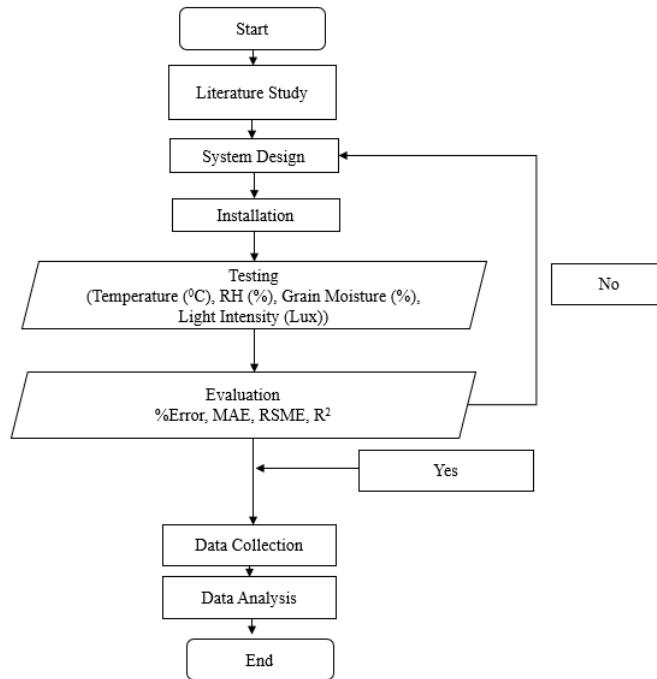


Figure 1. Research flowchart

b. Electronic Design

The electronic design shown in Figure 3 consists of a control system connected to a smartphone and a database connected via the internet to Google Firebase in the form of a website and smartphone app.

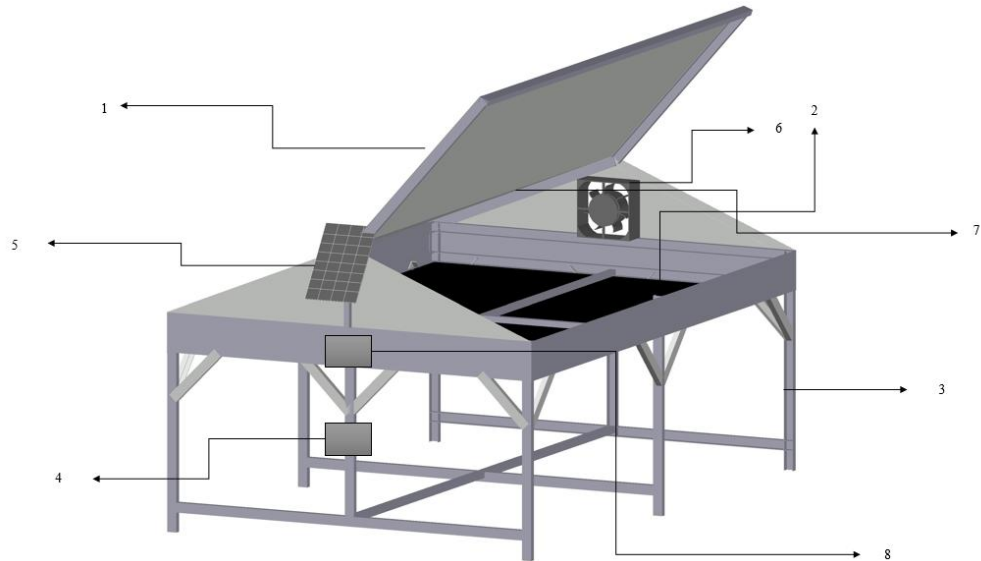


Figure 2. Solar Dryer Dome: 1). UV Plastics, 2). Drying Rack, 3). Stands, 4). Battery + BMS + Solar Charge Controller, 5). Solar Panel, 6). Exhaust, 7). Heater, 8). Control System.

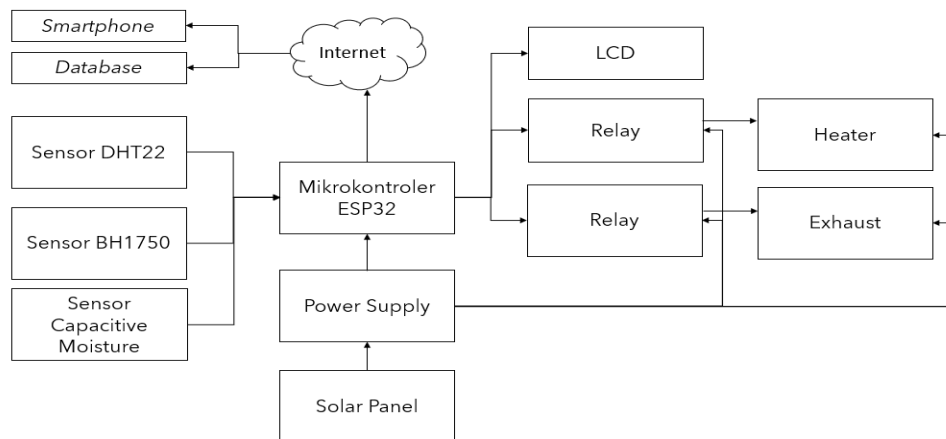


Figure 3. Electronic Circuit

c. Hybrid Operating Principle

The exhaust will turn on during the day and off at night or at temperatures below 200 °C, while the heater will turn on at night or at temperatures below 200 °C and off during the day or at temperatures above 300 °C.

2.4. Installation and Testing

The installation stage was carried out after the solar dryer dome and electronic circuit are complete to ensure all components are properly connected. The testing phase begins with calibration between the sensor and the measuring instrument used, specifically for temperature, relative humidity, light intensity, water content, and weight. The percentage error (%) is calculated by dividing the difference between the sensor measurement and the reference measuring instrument, then dividing the reference result by 100. The measurement is considered valid if the error value is <10%. Table 2 detailed different sensors used to measure temperature, relative humidity, light intensity along with the required conditions.

Table 2. Installation measurement

Parameters	Measuring Instrument	Sensor	Condition	Actuator
Temperature (°C)	<i>Thermometer</i>	DHT22	< 20 °C > 60 °C	Relay (Exhaust) On Relay (Exhaust) Off
Relative Humidity (%)	<i>Hygrometer</i>	DHT22	? %	Information
Light Intensity (lux)	<i>Luxmeter</i>	BH1750	< 1000 lux > 5000 lux	Relay (Heater) On Relay (Heater) Off
Grain Moisture (%)	<i>Grain Moisture</i>	Capacitive Soil Moisture	14% 12% 10%	Notification Notification Notification

2.4. Data Collection and Evaluation

2.4.1. Temperature and Humidity

Air temperature (0 °C) during the drying process plays a crucial role in accelerating the evaporation of water from the grains to be dried (Wahab *et al.*, 2025). Air humidity (%) indicates the amount of water contained in the air inside the solar dryer dome. Low humidity will easily absorb more water vapor from the grains, accelerating the drying process.

2.4.2. Solar Intensity

Light intensity during the drying process refers to the amount of sunlight entering the drying chamber, measured in lux (Lestari *et al.*, 2023). High solar intensity will generate greater heat, which increases the temperature and reduces the moisture content of the grains.

2.4.3. Grain Moisture Content

Moisture content is the ratio of the weight of water in a material to the total weight of the material, including water (Kurniawan *et al.*, 2020). Moisture content is an important parameter for measuring the quality and shelf life of grains and monitoring the drying process. Table 3 shows optimum moisture content based on Indonesian Standard (SNI).

Table 3. Indonesian National Standard (SNI) for grains

Grains	Wet Moisture Content (%)	Optimum Moisture Content (%)	SNI Number
Rice	22–28	14	SNI 6128:2015
Corn	30–35	14	SNI 01-3920-2009
Sorghum	25–30	14	SNI 01-7168-2006

2.5. Data Evaluation

Model evaluation calculates the Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and coefficient of determination (R²) (Zhu *et al.*, 2025) using the following formula:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \tag{1}$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \tag{2}$$

$$R^2 = 1 - \frac{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}{\frac{1}{n} \sum_{i=1}^n (y_i - \bar{y}_i)^2} \tag{3}$$

2.6. Data Analysis

This study used a completely randomized design (CRD) with four factors: temperature, humidity, water content, and sunlight intensity. Data analysis was performed using a t-test for the drying process using a solar dryer dome and conventional methods. The MAE, RMSE, and R2 tests were performed using Microsoft Excel 2019.

3. RESULTS AND DISCUSSION

3.1. Solar Dome Dryer Design

The Solar Dome Dryer (SDD), as depicted in Figure 4, is a drying system that utilizes solar energy by utilizing the microclimate. The structure is made of lightweight steel, C-channel lightweight steel battens, hollow sections, and UV plastic. The dimensions are 2 m × 1 m and the capacity is 25 kg. The power source is a solar panel, solar charge controller, battery, and inverter to power the control system, exhaust, and heater. The UV plastic functions to block solar radiation while maintaining temperature stability in the drying chamber.



Figure 4. Solar dome dryer, solar PV, and battery

The control system consists of three DHT22 temperature and humidity sensors: two inside and one outside the SDD. One BH2750 light intensity sensor is inside and one outside, and four grain moisture sensors are stored in each shelf inside the SDD. The controller box is connected to an ESP32 with a 2-channel relay and three I2C LCDs, the first of which displays temperature, humidity, light intensity, and grain moisture. Additionally, there's an ESP32 cam that operates individually but is connected to the same Google Firebase.

The drying system operates in a hybrid manner, utilizing solar energy during the day and equipped with a heater for nighttime operation or cloudy weather conditions (below 20 °C). When the exhaust is on, it automatically shuts off. Air circulation is controlled through an exhaust fan installed on the right side of the SDD, which accelerates the flow of hot air and reduces excess humidity in the drying chamber. An incandescent lamp heater equipped with a low-power circulation fan maintains a stable temperature at night, ensuring continuity of the drying process. The hybrid system is intended to optimize grain drying time.

The Smart Solar Dome Dryer is an integrated IoT monitoring and control system, consisting of sensors connected to an ESP32 microcontroller as a control center. Data is connected in real time to a Google Firebase-based smartphone application for remote monitoring. This system not only designs the solar dome dryer for drying but also utilizes renewable energy integrated with smart farming (Table 4)

Based on calculations under the lowest light intensity conditions (PSH 4) in Kalikidang Village, Sokaraja District, Banyumas Regency, the above specifications are sufficient to meet the exhaust needs for 12 h, but not enough to power the heater for 12 h. The battery can only store power for 10 h when fully charged, so it can only power the heater for 4 h. Therefore, if 24-h operation is desired, the solar panel capacity must be increased by using a larger battery. However, in this study, the maximum drying time is sufficient for 10.30 h, allowing the energy to dry rice, corn, and soybeans.

Table 4. Components and solar energy capacity in the solar dome dryer

Component	Capacity	Quantity
Solar Panel Polycarbonate Matsuyama	200 WP	2
Solar Charge Controller	30A	1
Baterai LiFePO4	12V 120 Ah 1,152 Wh (80%)	1
BMS	8s-24s	1
Inverter DC to AC	1.000 watt (90%)	1
Exhaust AC	56 W	1
Heater AC	50 W	2

3.2. Smart Solar Dome Dryer (Smart SDD)

The Smart SDD is designed to ensure automatic sensor data acquisition and system control and can be monitored remotely using the Internet of Things (IoT). The ESP32 is programmed to receive signals from the DHT22, BH1750, and Grain Moisture sensors, which are converted into digital information sent to the server. Programming is done using C++ on the Arduino IDE platform using a Wi-Fi network.

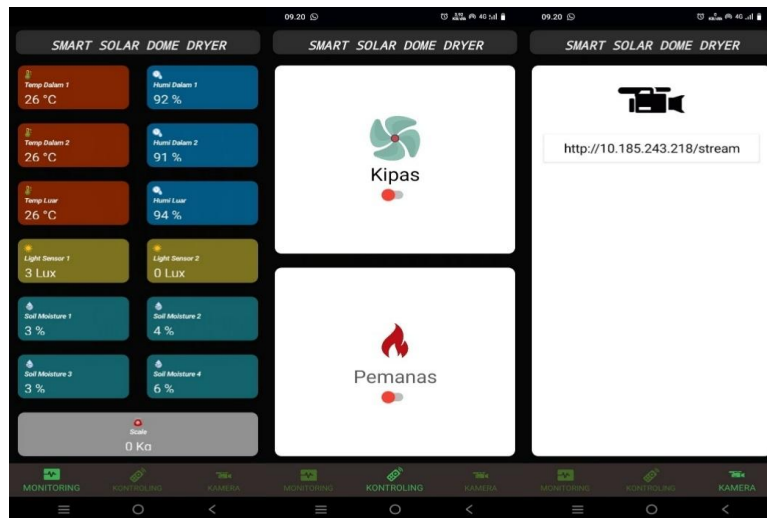


Figure 5. Smart solar dome dryer (SDD) display

Sensor data is sent in real time to Google Firebase as cloud-based storage, with integration displayed directly on a mobile smartphone. The application's display (Figure 5) consists of monitoring sections, namely: (1) Indoor Temp 1, (2) Indoor Temp 2, (3) Outdoor Temp, (4) Indoor Humidity 1, (5) Indoor Humidity 2, (6) Outdoor Humidity, (7) Light Sensor 1, (8) Light Sensor 2, and (9) Grain Moisture 1, 2, 3, and 4.

The second dashboard slide also displays the on/off status of the exhaust and heater, while the third slide displays a real-time video. The system also controls the exhaust and heater via relays. It also provides notifications if the temperature is below 20 °C or above 45 °C, as well as the on and off status of the exhaust and heater. The Smart SDD will provide a notification when the moisture content (%) reaches 12%, the standard moisture content for grains according to the Indonesian National Standard (SNI), and provides a recommendation for drying completion.

3.3. Sensor Calibration and Evaluation

This process involves comparing the sensor with a reference measuring instrument to determine its accuracy and consistency. The sensors used were the DHT22 temperature and humidity sensor, the BH1750 light intensity sensor, and the capacitive soil moisture sensor. Calibration was performed using four variables: % error, Mean Absolute Error (MAE), Root Mean Square Error (RSME), and coefficient of determination (R^2), all set to their original conditions.

Based on Table 5 the average % error of air temperature is 1.02%, while air humidity is 0.81%. So it can be concluded that the DHT22 sensor assessment is very accurate because it is close to 1%. While for MAE air temperature is 0.29 °C and air humidity is 0.63%, also shows DHT22 is very accurate because the temperature is less than 0.5 °C and humidity is less than 5%. While based on RSME calculations the average air temperature is 0.50 °C less than 1% with a relative humidity of 0.66% less than 1% so it is accurate and suitable for use for temperature and humidity control. While based on the coefficient of determination (R²) the air temperature is 0.983 with a humidity of 0.990, the difference is only 0.19 °C and 0.53% or close to 1 (perfect value) so the DHT22 sensor value is very consistent and has a very accurate linear relationship with a comparative measuring instrument, namely a thermohygrometer.

Table 5. Calibration of DHT22 Sensor

Time	DHT22 Temperature (°C)	Thermo meter (°C)	DHT22 Humidity (%)	Hygro meter (%)	% Error Temperature	% Error Air Humidity	MAE Temperature	MAE Air Humidity	RMSE Temperature	RMSE Air Humidity
08:00	29.40	29.20	78.20	77.50	0.68	0.90	0.20	0.70	0.20	0.70
09:00	29.80	28.50	77.00	76.20	4.56	1.05	1.30	0.80	0.93	0.75
10:00	31.20	31.20	73.80	73.00	0.00	1.10	0.00	0.80	0.76	0.77
11:00	32.60	32.50	70.50	70.00	0.31	0.71	0.10	0.50	0.66	0.71
12:00	33.80	33.60	67.90	67.30	0.60	0.89	0.20	0.60	0.60	0.69
13:00	34.50	34.20	66.50	66.10	0.88	0.61	0.30	0.40	0.55	0.65
14:00	34.20	34.40	66.80	66.80	0.58	0.00	0.20	0.00	0.52	0.59
15:00	33.60	33.70	68.00	68.70	0.30	1.02	0.10	0.70	0.48	0.59
16:00	32.10	30.20	70.20	69.50	6.29	1.01	1.90	0.70	0.69	0.60
17:00	30.40	30.20	73.50	74.00	0.66	0.68	0.20	0.50	0.65	0.58
18:00	29.00	28.90	76.20	75.50	0.35	0.93	0.10	0.70	0.61	0.59
19:00	27.80	27.60	79.00	78.30	0.72	0.89	0.20	0.70	0.58	0.60
20:00	26.60	26.40	81.20	80.50	0.76	0.87	0.20	0.70	0.56	0.61
21:00	25.80	25.70	82.40	81.70	0.39	0.86	0.10	0.70	0.53	0.62
22:00	25.10	25.00	83.00	82.50	0.40	0.61	0.10	0.50	0.51	0.61
23:00	24.60	24.50	83.80	83.00	0.41	0.96	0.10	0.80	0.49	0.62
00:00	24.20	24.00	84.20	83.50	0.83	0.84	0.20	0.70	0.48	0.63
01:00	23.80	24.10	84.80	84.00	1.24	0.95	0.30	0.80	0.47	0.64
02:00	23.50	23.30	85.00	84.40	0.86	0.71	0.20	0.60	0.45	0.64
03:00	23.30	23.60	85.20	84.60	1.27	0.71	0.30	0.60	0.44	0.63
04:00	23.10	22.90	85.40	84.70	0.87	0.83	0.20	0.70	0.43	0.64
05:00	23.50	23.60	84.80	84.10	0.42	0.83	0.10	0.70	0.42	0.64
06:00	24.00	23.90	83.50	82.90	0.42	0.72	0.10	0.60	0.41	0.63
07:00	25.20	25.40	82.00	81.30	0.79	0.86	0.20	0.70	0.50	0.66

Table 6. Calibration of BH1750 sensor

Time	BH1750 (lux)	Lux Meter (lux)	% Error	MAE	RMSE
08:00	29,218.7	29,067.8	0.52	150.9	22,771.8
09:00	45,570.2	43,888.1	3.83	1,682.1	2,829,483.9
10:00	63,598.3	63,750.0	0.24	151.7	23,041.9
11:00	79,424.7	83,090.3	4.41	3,665.6	13,435,557.7
12:00	88,758.6	85,056.7	4.35	3,701.9	13,693,658.6
13:00	88,758.6	85,056.8	4.35	3,701.8	13,693,002.6
14:00	79,424.7	83,313.4	4.67	3,888.7	15,119,999.7
15:00	63,598.3	64,130.8	0.83	532.5	283,557.8
16:00	45,570.2	43,133.4	5.65	2,436.8	5,938,015.6
17:00	29,218.7	29,134.8	0.29	83.9	7,040.6
18:00	16,764.3	15,873.0	5.62	891.3	794,417.7
19:00	8,607.1	8,148.5	5.63	458.6	210,322.0
20:00	3,954.3	3,883.5	1.82	70.8	5,016.6
21:00	0.0	0.0	0.00	0.0	0.0

Based on Table 6, it is concluded that the average % error is 3.45%, the Mean Absolute Error (MAE) value is 1,530 lux or 1.7%, the Root Mean Square Error (RSME) is 2,074 lux or around 2.4% with a coefficient of determination (R^2) of 0.999 or close to 1 so that the BH1750 sensor is suitable for monitoring light intensity with very high accuracy.

Table 7. Calibration of capacitive soil moisture sensor

Sample	Capacitive Soil Moisture (%)	Grain Moisture TS-1 (%)	% Error	MAE	RMSE
Rice Grain 1	12.25	12.50	2.00	0.25	0.0625
Rice Grain 2	13.48	13.20	2.12	0.28	0.0784
Rice Grain 3	14.12	14.10	0.14	0.02	0.0004
Rice Grain 4	12.72	12.80	0.63	0.08	0.0064
Rice Grain 5	13.50	13.60	0.74	0.10	0.0100
Corn 1	14.08	14.00	0.57	0.08	0.0064
Corn 2	13.40	13.50	0.74	0.10	0.0100
Corn 3	12.02	12.00	0.17	0.02	0.0004
Corn 4	14.00	14.10	0.71	0.10	0.0100
Corn 5	13.40	13.50	3.70	0.50	0.2500
Sorghum 1	13.40	13.30	0.75	0.10	0.0100
Sorghum 2	12.10	12.00	0.83	0.10	0.0100
Sorghum 3	12.60	12.50	0.80	0.10	0.0100
Sorghum 4	14.06	14.00	0.43	0.06	0.0036
Sorghum 5	13.48	13.50	0.15	0.02	0.0004

Based on the data in Table 7 above, the average percentage error is 0.97%, with a Mean Absolute Error (MAE) of 0.13 and a Root Mean Square Error (RMSE) of 0.18. These values are less than 1% and are considered very small, thus providing very high measurement accuracy and consistency, making them suitable for measuring grain moisture content.

3.4. Environmental Parameter Monitoring

During the drying process, temperature (0 °C), humidity (%) and light intensity (lux) influence moisture content and drying time. This is because environmental parameters are a determining factor in hybrid drying using a solar dome dryer. The process also takes into account the specifications of the solar energy used to obtain optimal calculations.

Table 8. Environmental parameters in the SDD drying room

Commodity	Ambient Temperature (°C)	SDD Temperature (°C)	Ambient RH (%)	SDD RH (%)	Ambient Light Intensity (lux)	SDD Light Intensity (lux)
Rice Grain	33.12	40.92	64.30	57.50	84,397	101,940
Red Rice Grain	30.15	40.15	70.70	56.90	79,323	105,000
Glutinous Rice Grain	29.88	41.91	68.60	57.50	80,203	101,940
Black Glutinous Rice	31.50	39.09	64.80	49.90	75,726	105,000
Feed Corn	30.10	39.35	68.50	55.50	78,367	102,000
Sweet Corn	28.28	39.20	70.90	59.00	82,979	103,000
Glutinous Corn	28.91	39.20	72.80	59.00	81,867	101,000
White Sorghum	29.67	39.65	70.10	39.50	83,142	105,000
Brown Sorghum	29.18	39.65	68.20	42.50	79,647	101,940
Red Sorghum	30.20	39.65	71.40	42.50	79,737	105,000

The drying process yielded average temperature, humidity, and light intensity values as shown in Table 8. All data collection was conducted during the day, which served as a reference for drying time. The use of the Solar Dome Dryer increased air temperature by 32.5%, humidity by 25%, and light intensity by 28.1% from the ambient or natural environmental conditions. The increased temperature parameter, coupled with decreased humidity, coupled with light intensity, accelerated the drying process. These changes created a hotter, drier, and brighter environment, thus supporting a faster drying process compared to conventional drying. The comparison results are presented in Figure 8.

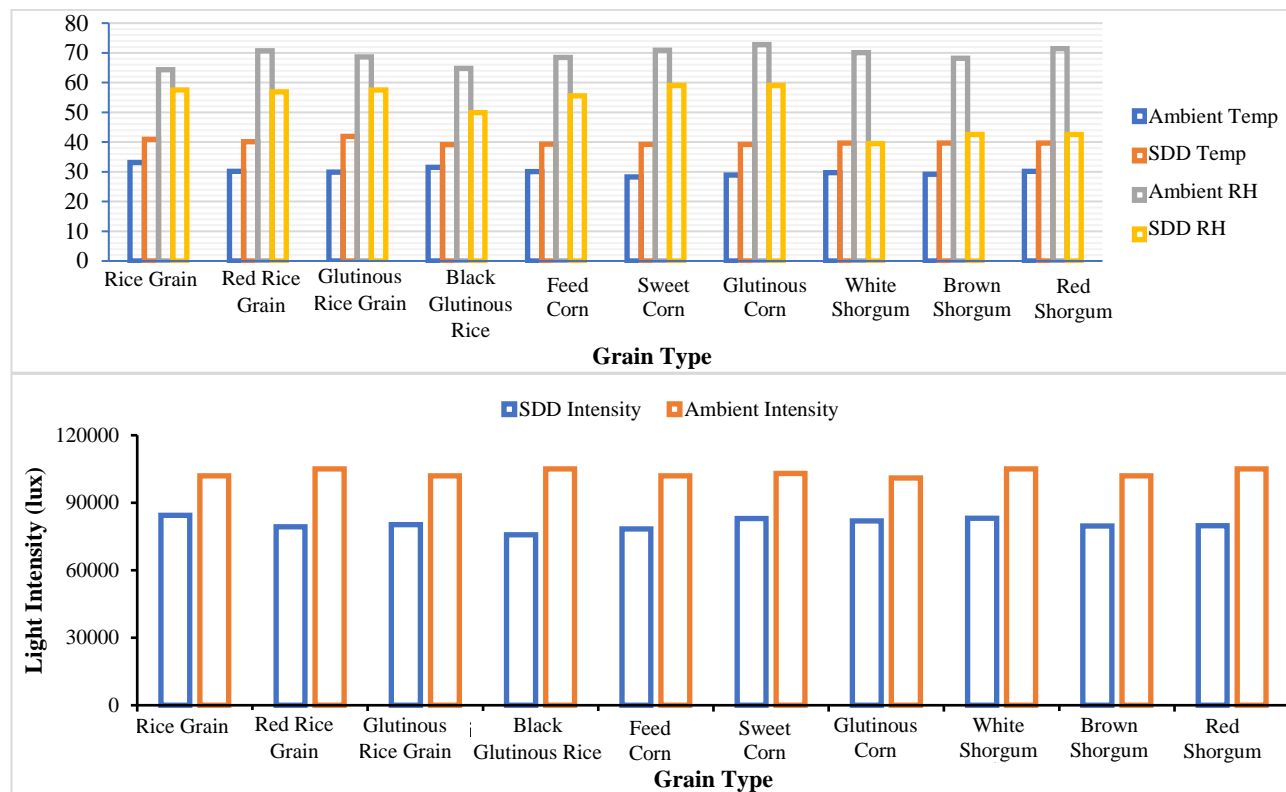


Figure 8. Comparison of temperature, humidity and light intensity between SDD and the actual environment.

3.5. Grain Moisture Content

Grain moisture content is determined based on changes from the initial harvest, followed by drying until optimal moisture content is achieved for storage. The drying process is influenced by temperature, humidity, and light intensity, which influence drying speed. Furthermore, the initial moisture content and the material also influence drying time; higher initial moisture content results in longer drying times. The drying time for unhusked rice was significantly faster than the 2–4 days reported in research (Austria *et al.*, 2024), which required only 4.72 h. The comparison result among cereal grains are presented in Table 9.

Table 9. Moisture content of grain drying using SDD and drying time required for different grains.

Grain Type	Initial Moisture Content (%)	Optimal Moisture Content (%)	Drying Duration (h)
Rice Grain	20.50	12.00	4.72
Red Rice Grain	32.60	12.00	6.20
Glutinous Rice Grain	25.50	12.00	5.49
Black Glutinous Rice	38.50	12.00	6.62
Feed Corn	53.20	12.00	7.35
Sweet Corn	60.40	12.00	7.62
Glutinous Corn	51.10	12.00	7.27
White Sorghum	32.60	12.00	6.20
Brown Sorghum	30.20	12.00	5.99
Red Sorghum	26.60	12.00	5.62

3.6. Drying Time Performance

The drying time of the research conducted using the Solar Dome Dryer (SDD) is expected to accelerate the drying process, especially during the rainy season. Conventional drying poses problems if environmental conditions are unfavorable; its use is more optimal during the rainy season. The research was conducted in sunny weather with

relatively stable temperature, humidity, and light intensity, reaching a maximum drying room temperature of 36 °C. During the rainy season, drying rice grain from a moisture content of 20.50% to an optimal 12% took 6.50 h, still faster than conventional drying, which requires 7.40 h. This occurs because the temperature and light intensity in the SDD are higher than the actual environment, accelerating the drying process as presented in Table 10.

Table 10. Comparison of drying duration for each grain

Commodity	Drying Duration (h) – SDD	Drying Duration (h) – Conventional
Rice Grain	4.72	7.40
Red Rice Grain	6.20	8.88
Glutinous Rice Grain	5.49	8.18
Black Glutinous Rice	6.62	9.30
Feed Corn	7.35	10.04
Sweet Corn	7.62	10.30
Glutinous Corn	7.27	9.95
White Sorghum	6.20	8.88
Brown Sorghum	5.99	8.67
Red Sorghum	5.62	8.31

Based on the analysis of variance (ANOVA), the *F*-table (4.54) was greater than the *F*-crit (4.41), indicating a significant difference with a *p*-value of 3.93×10^{-5} , less than 0.05 at the 5% level. Comparisons during the rainy season were not possible because conventional drying was not possible, while SDD was able to dry the grains, although not as optimally as in severe weather. Therefore, it can be concluded that drying time with the Solar Dome Dryer is faster than conventional methods, as seen in Figure 9.

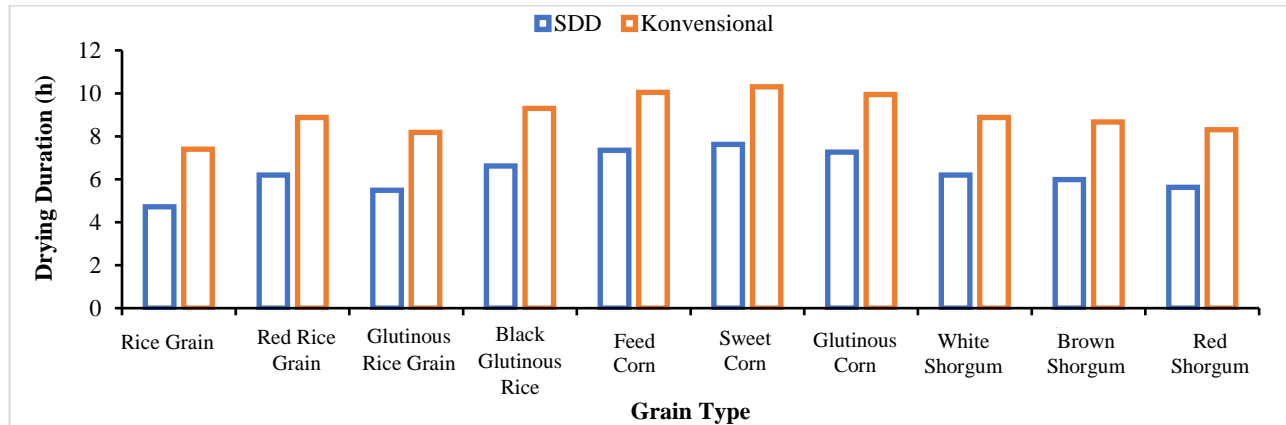


Figure 9. Comparison of drying time between SDD and conventional drying for different grains

4. CONCLUSIONS AND SUGGESTIONS

The Solar Dome Dryer (SDD) is designed for a hybrid grain drying process using lightweight steel and UV plastic, measuring 2m x 1m, with a capacity of 25 kg. The exhaust and heater operate alternately during the day and night based on DHT22 and BH1750 sensors, as well as capacitive soil moisture sensors. An automated, IoT-integrated hybrid system uses the Smart Solar Dome Dryer (Smart SDD) application to control and monitor drying room conditions. Sensor evaluation revealed that the % error, MAE, RMSE, and R2 were all below 1%, thus declaring the sensor valid. At an average temperature of 40°C, RH 59%, and 101,940 lux, the drying time to achieve a final moisture content of 12% for the grains was 4.72–7.62 h. ANOVA analysis showed that drying using the SDD was faster than conventional drying, especially during the rainy season.

Further research can utilize Artificial Intelligence (AI) to optimize the drying process using deep learning or machine learning. Other grains that require longer drying duration can be explored, such as coffee, cacao, cardamom, cloves, and others.

AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
HAL	✓	✓	✓			✓	✓		✓			✓	✓	✓
LW	✓	✓		✓		✓	✓	✓		✓				
TAY	✓	✓			✓	✓	✓			✓	✓			
C: Conceptualization					Fo: Formal Analysis				O: Writing - Original Draft					Fu: Funding Acquisition
M: Methodology					I: Investigation				E: Writing - Review & Editing					P: Project Administration
So: Software					D: Data Curation				Vi: Visualization					
Va: Validation					R: Resources				Su: Supervision					

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