Dehydration of Moringa leaves using microcontroller and IoT controlled electrical dryer

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ABSTRACT

The dehydration of Moringa Oleifera leaves is crucial to preserving their high nutritional value and extending shelf life for use in food and pharmaceutical applications. Traditional drying methods often result in nutrient degradation and lack precise environmental control. This study presents the design and implementation of an internet of things (IoT)-enabled electrical dryer system controlled by a microcontroller for the efficient dehydration of Moringa leaves. The system integrates temperature and humidity sensors, an Arduino Mega microcontroller, and a web-based interface for real-time monitoring and control. The electrical dryer maintains optimal drying conditions, significantly reducing moisture content while preserving essential nutrients. Data is logged and visualized through IoT connectivity, allowing for remote access and performance analysis. The dehydration of Moringa leaves requires approximately one kg of electricity for batteries in dual-energy dryers, which are based on microcontrollers and the IoT. The results demonstrate that the proposed system offers a reliable, energy-efficient, and scalable solution for the controlled dehydration of Moringa leaves, with potential applications in smart agriculture and postharvest processing. The excellent drying time is achieved in a greenhouse dryer, which maintains a temperature of 45 °C within the drying chamber, resulting in a median drying time of 6 hours. The standard moisture percentage of clean and dry Moringa leaves is measured at 18.5% (wb) and 8% (wb), respectively.

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1. INTRODUCTION

Drying removes moisture from Moringa Oleifera plants after harvesting, which is a significant problem due to the climate, and this issue persists despite the use of traditional drying systems [1]. Postharvest leaves typically contain a moisture content of around 19% to 18.5% Wb, which is not ideal for storage, as it can cause discoloration, deterioration, and mold growth, thereby increasing the likelihood of pest infestation [2]. This can lead to a decrease in the nutritional benefits of Moringa Oleifera leaves [3]. Therefore, it is crucial to dry the leaves as soon as possible after harvest, preferably within 24 hours [4]. Delayed, incomplete, or inefficient drying reduces the quality of the leaves and causes losses [5]. Many applications utilize automated leaf dryers, allowing crops to be harvested at any time of the year and stored for extended periods [6]. Drying to the optimum moisture content level extends the shelf life of the leaves

[7], [8]. The workload and stress on farmers are significantly reduced, allowing them to use this time for other purposes [9]-[11]. An automated drying system can complete the drying process within a few hours, thereby reducing crop losses, including leaves falling from the tree [12]-[15]. It also helps reduce the dependence on harvesting and drying on weather conditions. There are several conventional drying methods, including solar bubble drying, layer drying, natural low-temperature airflow drying, and continuous airflow drying [16]. Mechanical drying of agricultural products is a power-intensive process in postharvest technology [17], [18]. More emphasis is being placed on solar assets to address the scarcity of fossil fuels [19]. A novel solar dryer utilizing natural convection, combined with a solar air heater and a drying chamber, has been developed. Due to the low temperature, the initial moisture content cannot be adequately dried using natural airflow [20]. It also requires a power supply for each basket for the fan motor of the dryer. This results in increased financing costs and also requires certified and skilled personnel. The most common problem with this drying technique is that it is a conventional method requiring a significant amount of space and time. Depending on the climatic conditions, the initial cost can be very high. Solar-powered and battery-powered automatic Moringa leaf dryers have been developed to overcome the above problems. The use of IoT in crop processing is a novel approach in this study. There is no integration of the IoT in the leaf drying system, prevents remote control and monitoring. IoT-enabled dryers can provide real-time data logging and notification, which is not commonly found in previous research studies on the application of Moringa Oleifera leaf dryers.

The proposed idea has been implemented to shorten the postharvest period for farmers. The motorized aluminium mesh and stainless steel horizontal rotating cylinder are well-suited to position the Moringa leaves allowing them to penetrate the hot air easily and effectively penetrate the hot air. This device uses an Arduino Mega to control movements intended for the drying process intelligently. The herbal solar drying approach, which uses solar heat to dry agricultural products for 10 to 5 days, can become dull and monotonous. Following the same principle, this paper utilizes heat generated by heating elements and sunlight, combined with a fan, to produce uniform heat that meets the desired specifications and standards for drying the leaves.

2. METHODOLOGY

The primary objective of this newsletter is to simplify, expedite, and enhance the efficiency of farmers' practices associated with grain drying and postharvest storage [21]. The designed mechanism calls for shorter leaf drying times through solar PV drying compared to conventional methods and aims to reduce labor-intensive farming. Components used to remedy this trouble consist of a solar panel, buck-boost converter, charge controller circuit, Johnson DC gear motor (20 RPM), Arduino Mega, temperature and humidity sensor (DHT11), 5 V twin channel relay, motor bridge, circuit driver, heater element, DC fan, displacement chain, motherboard, and lead wires.

2.1. Function block diagram

The easy and automated dual-feed Moringa leaf dryer is designed to dry Moringa leaves efficaciously and quickly. The dryer features a simple structure that allows for easy assembly and disassembly of its components. The block diagram of the dryer is shown in Figure 1. The running precept of every block is defined in this section. The circuit machine includes solar panels, controllers, batteries, and charging circuits. The solar panel provides energy to charge the battery during in the day, which is then used to power the machine. At night, the battery serves as an energy storage facility for the farmhouse's electrical lights. A solar charge controller controls the battery charge.

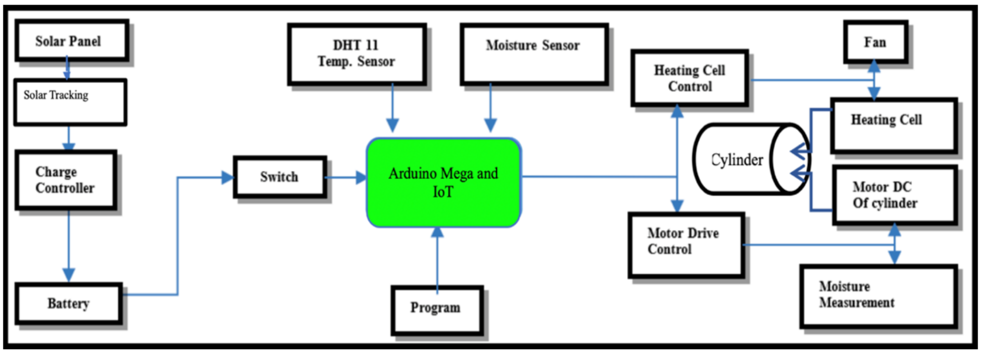

Figure 1. Functional block diagram

2.2. Control circuit working

From the 12 V/100 AH lithium-ion battery, the voltage is reduced to 5 V using a buck converter, which is then fed to the Arduino Mega and the DC motor as the power source. The horizontal cylinder is designed to rotate at a very low speed of 20 rpm, which is achieved by the Johnson DC gear motor. The Arduino Mega is the main microcontroller used in the dryer. The drying system contains a temperature and humidity sensor to detect the temperature of the heating space. Light-dependent resistor sensor to check for a 90° angle on the solar panel, a heating element to heat the room, a DC fan to push hot air excess discharge from the cylinder, and the bridge motor driver circuit to control the DC gear motor speed. Both temperature and humidity sensors provide input to the Arduino Mega, as well as light-dependent resistors (LDRs) in two numbers [22].

2.3. Temperature sensor control works

The temperature sensor senses the heating temperature inside the chamber and maintains the permissible temperature range of 35 °C to 60 °C. The fan is designed to operate only within this permissible temperature range, which helps blow hot air into the acrylic tube. The dual-channel relay module cuts off power to the heater when the perceived temperature falls outside the allowable range.

2.4. Moisture sensor control working

At night, the battery serves as an energy storage facility for the farmhouse's electrical lights. A solar charge controller controls the battery charge. The dryer model shown in Figure 2 was designed in SketchUp software. Understand the design and sizing aspects of all hardware components involved in the project. The outer shell dimensions are 575×430 mm, while each horizontal cylinder measures 360×360 mm. The control panel is centered on the wall in the cabinet, allowing all cables and components to be arranged and operated from one place. There are two DC fans in the heating duct, and two heating elements enable them to supply hot air to the Moringa leaves as noted in [23].

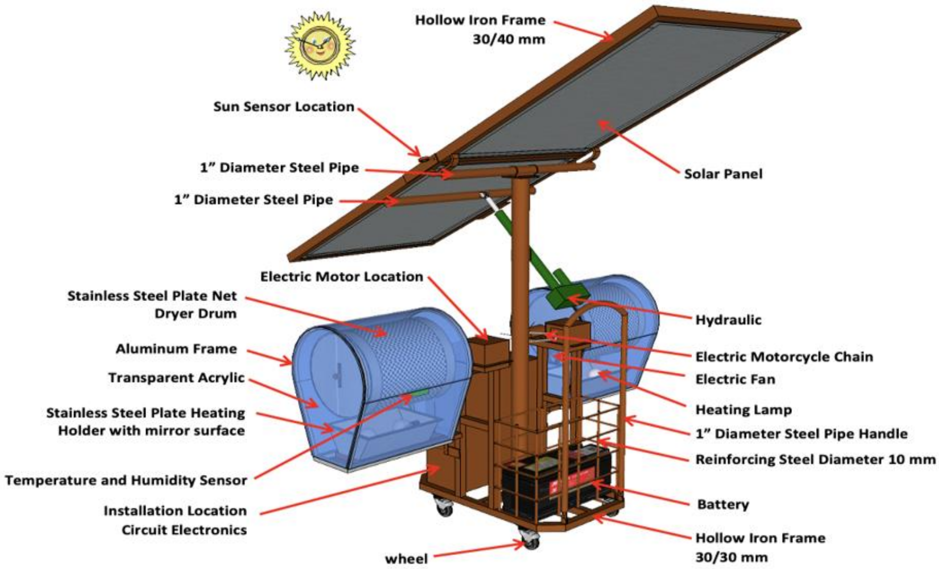

Figure 2. Schematic diagram of the prototype treatment

2.5. Experimental setup

The hardware structure is designed as shown in Figure 2. The horizontal cylinder is made of mesh for flexibility and features holes that allow air to enter through the Moringa oleifera leaf plate and the cylinder tube. The coding of Arduino Mega is based on the requirements and connections to the various components. This section gives a detailed description of the dryer's experimental setup. Arduino Mega interface, temperature and amplifier; humidity sensor, relay, and DC fan: The Arduino A0 pin is connected to the data pin of the DHT11 temperature and humidity sensor; the voltage common collector (VCC) and ground (GND) pins are powered. The relay module is connected to pins A1 and A2 of the Arduino, and the DC fan is internally connected to the relay that provides the switching action.

2.6. Interfacing of Arduino Mega, temperature and humidity sensor, relay, and DC fans

The interfacing of an Arduino Mega with a temperature and humidity sensor, relay, and DC fans enables the development of an efficient environmental control system. The temperature and humidity sensor DHT11 continuously monitors real-time atmospheric conditions and sends the data to the Arduino Mega for processing. Based on the programmed threshold values, the Arduino activates the relay module, which acts as a switch to control the DC fans, ensuring safe operation without directly connecting high-current components to the microcontroller. This setup provides an automated and reliable mechanism for maintaining optimal environmental conditions, commonly applied in smart agriculture, greenhouse monitoring, and indoor climate control systems. Pin A0 of the Arduino is connected to the data pin of the DHT11 temperature and humidity sensor, while the VCC and GND pins are connected to the supply. The relay module connects the A1 and A2 pins of the Arduino, and the DC fans are internally connected to the relay, providing the switching actions [24].

2.7. Heater control

The heater control, a temperature sensor, and a humidity sensor are defined as inputs to the Arduino Mega on pins A0 and A1, respectively. Arduino then uses the temperature and humidity readings to define a control strategy. A crucial step is to regulate the fan's speed and the heating element's temperature, as this can cause the leaves to dry out, leading to their premature fall and subsequent rot. After numerous trials and errors, the temperature value was set correctly. Since the moisture content of Moringa leaves should be between 10% (wb) and 8% (wb), this value was predetermined and fixed [25].

2.8. Arduino Mega interface, humidity sensor, bridge motor driver IC

For the speed of a horizontal cylindrical DC motor, which runs at a constant speed of 20 rpm, the humidity sensor value is an important parameter that provides input to the Arduino Mega. As previously mentioned, the ideal moisture content for storing Moringa leaves for 6-12 months is around 8%-10%, so the moisture content value of the Moringa leaves in this program has a range of 8% Wb to 10% Wb [27]. All control circuits are connected, placed on a suitable platform, and centered on the wall of the box. The Arduino Mega is used to control the entire circuit. Connections to the Arduino Mega are made from temperature and humidity sensors, motor driver ICs, and LDRs [26]. These connections form the control circuit for the hydraulic motor driver and humidity sensor. These connections form the control circuit for the heating element. Connections to the Arduino Mega come from an IoT transmitter sensor, temperature and humidity sensors, a dual-channel 5 V relay module, and a circuit board.

Figure 3 illustrates the experimental setup of the dual-energy solar dryer system. The control unit, as shown in Figure 3(a), integrates a microcontroller with IoT capabilities, maximum power point tracking (MPPT), relays, an inverter, an LCD, and a DC motor for operational regulation. The drying chamber, as shown in Figure 3(b), consists of an acrylic cylinder tube and an aluminium cylinder equipped with heating lamps and a hydraulic mechanism to support uniform drying. The solar panels, equipped with a solar tracker and solar meter as shown in Figure 3(c), supply renewable energy and enable real-time performance monitoring of the system.

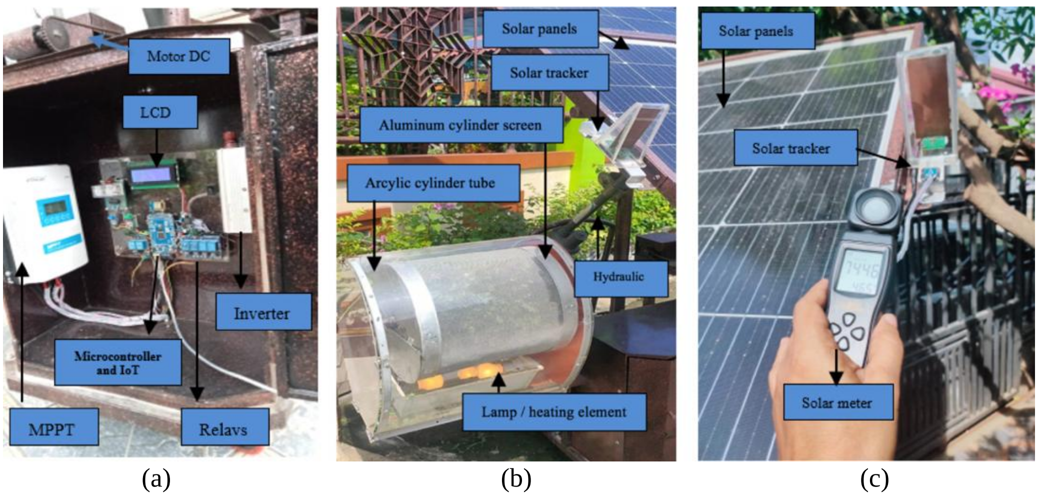

Figure 3. Experimental setup of the dual-energy solar dryer system: (a) control unit, (b) drying chamber, and (c) solar panel with tracker

3. RESULTS AND DISCUSSION

The prototype model of a dual-energy automatic Moringa leaf dryer shows that farmers can feel comfortable, and the drying process is completed in a few hours. The system is designed using a horizontal rotating cylinder, where Moringa leaves are circulated with hot air and thoroughly dried evenly with the help of a heating element, direct sunlight, and a fan mounted on an acrylic tube. The hot air will draw moisture from the Moringa leaves, allowing them to dry to the desired level, ideally suited for storage. The value displayed on the Arduino Mega serial monitor is validated using a grain moisture meter and a lux meter to ensure consistency. Tables 1 and 2 show recorded humidity readings and temperature humidity at different power levels.

Tables 1, 2, 3, 4, and Figures 4, 5, and 6 present a consolidation of various outputs, including temperature, humidity, and moisture content, obtained from the Arduino Mega serial monitor. The readings were tabulated after some trial and error using IoT from dried Moringa leaves in two horizontal cylinders made of aluminium and stainless steel. The serial monitors show results periodically. There are slight variations in the temperature and humidity values read by the humidity sensor, as these sensors are designed for high-accuracy detection. Thingspeak.com is used as a web to display temperature and humidity measurement data every 5 seconds from a prototype that performs the drying process of Moringa leaves.

Based on the data in Tables 1 and 2, as well as Figure 4, the initial conditions are as follows: the water content is 19.5%, and the initial power measured on the battery is 18.85 watts. During the drying process of Moringa leaves, the battery is also charging, so within 4 hours, it reaches the capacity limit. During the charging condition, the drying process is reduced by 3% to 16.5%. The drying process on the first day was carried out for 6 hours, with maximum battery usage occurring from 12:00 to 13:00. After the battery reached its maximum condition, the drying process continued on the battery until 15:00. During these 3 hours, the water content in the Moringa leaves dropped to 15%, and the battery capacity on the first day became 86.50 watts. The next day, the battery capacity was initially at 70.55 watts while the water content was 16%. On this day, the battery is charged simultaneously with the drying process of the Moringa leaves. It can be observed that the battery capacity increases when solar panels are used as a charging source. In this process, the water content in Moringa leaves drops by 3.5% to 12.5%. The drying process continues until the third day, when the moisture content remains 10% in 13 experiments.

From Tables 1, 2, and Figure 4, a comparison is made with the aluminium material. The same battery usage, power, and number of Moringa leaves are also used out with stainless steel cylinder material. According to these data, it is evident that the water content on the first day decreased by 4.5%, and the maximum battery capacity was achieved between 12:00 and 13:00. During the period of maximum battery capacity usage, the moisture content in Moringa leaves decreased by 2%. With the same power capacity, the next day, within 4 hours, the battery's condition has improved because it receives a charge from the solar panels. During the drying process, the water content in Moringa leaves decreased by 3.5%. The drying process was continued the next day until the moisture content reached 9% in 13 experiments. The battery capacity doubled from the previous 48.15 watts on the third day due to optimal sunlight.

Table 1. Moisture content on battery charging in the drying process of one kg of Moringa leaves using a stainless-steel cylinder with 200 watts of power

Day	Experiment	Time	Moisture content (%)	P (Watt)
First day	1	09.00 – 10.00	19.5	18.85
First day	2	10.00 – 11.00	18	199.48
First day	3	11.00 – 12.00	17	118.78
First day	4	12.00 – 13.00	16.5	209.67
First day	5	13.00 – 14.00	16	15.64
First day	6	14.00 – 15.00	15	86.50
Second day	7	12.00 – 13.00	16	70.55
Second day	8	13.00 – 14.00	14.5	62.63
Second day	9	14.00 – 15.00	13.5	45.86
Second day	10	15.00 – 16.00	12.5	86.92
Third-day	11	09.00 – 10.00	12	48.15
Third-day	12	10.00 – 11.00	11.5	91.63
Third-day	13	11.00 – 12.00	10	96.91

Based on Table 3 and Figure 5, the drying process of 3 kg of Moringa leaves is conducted over 1 day, lasting 6 hours, until the water content drops from 19.5% to 8.5%. This occurs from the initial battery capacity of 47.39 watts at 09.00. During the drying process, the battery capacity increased at 11.00 A.M. due to the quite optimal battery charging process and sufficient sunlight. At 11.00 A.M, the battery capacity reached 128.18 watts, and during the charging process, the water content in the Moringa leaves dropped by

4.5%. Then the battery capacity decreased from 128.18 watts to 65.99 watts. During this process, the water content in Moringa leaves drops by 4%. The drying process was continued until the moisture content reached 8.5%, down from 11%. For battery capacity, with a water content ranging from 11% to 8.5%, the battery is charged to increase its capacity to 133.69 watts, and the water content reaches 8.5% in six experiments.

Table 2. Moisture content battery charging during the drying process of one kg of Moringa leaves utilizes an aluminium cylinder with a power of 200 watts

Day	Experiment	Time	Moisture content (%)	P (Watt)
First day	1	09.00 – 10.00	19.5	18.85
First day	2	10.00 – 11.00	17	199.48
First day	3	11.00 – 12.00	16.5	118.78
First day	4	12.00 – 13.00	16	209.67
First day	5	13.00 – 14.00	15	15.64
First day	6	14.00 – 15.00	14	86.50
Second day	7	12.00 – 13.00	15.5	70.55
Second day	8	13.00 – 14.00	14	62.63
Second day	9	14.00 – 15.00	13	45.86
Second day	10	15.00 – 16.00	12	86.92
Third-day	11	09.00 – 10.00	11	48.15
Third-day	12	10.00 – 11.00	10.5	91.63
Third-day	13	11.00 – 12.00	9	96.91

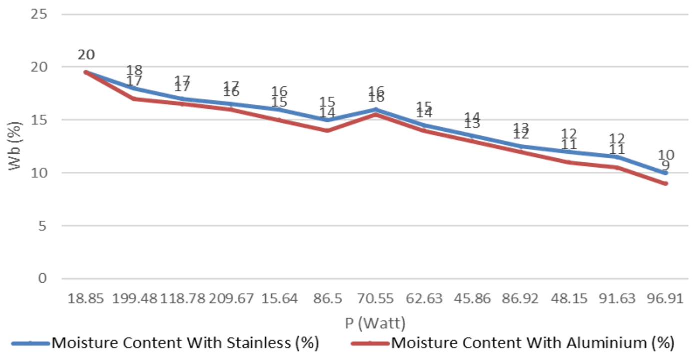

Figure 4. Graph of the relationship between dehydration and the moisture content of one kg of Moringa leaves in aluminium and stainless-steel horizontal cylinders with a drying power of 200 watts

Based on Table 4 and Figure 6, the initial battery capacity is 150.3 watts, with an initial moisture content of 19.5% in the Moringa leaves. When the water content decreases by 1%, the battery capacity increases to 207.78 watts. Over 4 hours, the water content in Moringa leaves dropped to 14% but the battery capacity dropped dramatically to 19.57 watts. To achieve a moisture content of 9%, the battery is charged until its capacity reaches 83.25 watts, while the water content in Moringa leaves has reached 9% in the 7th experiment.

Table 3. Battery charging in the drying process of one kg of Moringa leaves using a horizontal cylindrical aluminium with 400 watts of drying power

Day	Experiment	Time	Moisture content (%)	P (Watt)
First day	1	08.00 – 09.00	19.5	47.39
First day	2	09.00 – 10.00	18	62.76
First day	3	10.00 – 11.00	15	128.18
First day	4	11.00 – 12.00	13	83.57
First day	5	12.00 – 13.00	11	65.99
First day	6	13.00 – 14.00	8.5	133.69

Table 4. Battery charging in the drying process of one kg of Moringa leaves using a horizontal cylindrical stainless steel with 400 watts of drying power

Day	Experiment	Time	Moisture content (%)	P (Watt)
First day	1	09.00 – 10.00	19.5	150.30
First day	2	10.00 – 11.00	18. 5	207.78
First day	3	11.00 – 12.00	17.5	177.99
First day	4	12.00 – 13.00	16.5	147.47
First day	5	13.00 – 14.00	14	19.57
First day	6	14.00 – 15.00	11.5	166.51
First day	7	15.00 – 16.00	9	83.25

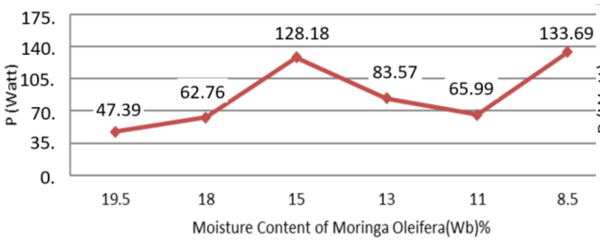

Figure 5. Graph of the moisture content of Moringa leaves in a horizontal cylindrical aluminium with 400 watts of drying power

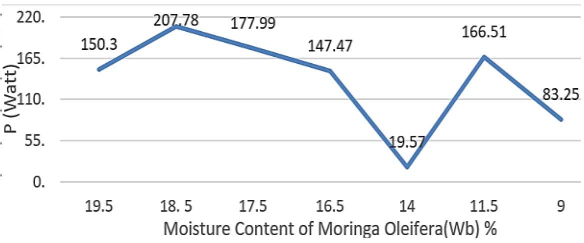

Figure 6. Graph of the moisture content of Moringa leaves in a horizontal cylindrical stainless steel with 400 watts of drying power

3.1. Battery performance of the dual energy dryer system

The use of maximum power point tracking (MPPT) to drive electrical equipment in a dual-energy dryer prototype, based on a microcontroller and the IoT, is presented as a means to improve the efficiency of solar panels and enhance the performance of the dryer prototype. With the maximum power point tracker, the system starts from the maximum power point (MPP). It produces its maximum power output by measuring the maximum solar radiation falling on the photovoltaic module. The maximum power point tracker solar charge controller transfers electricity from a higher voltage level to a lower voltage level by acting as a DC-DC transformer. The output current will be greater than the input current if the output voltage is smaller than the input voltage.

The measurement results shown in Figure 7 illustrate the battery charging process during testing from morning to evening. The graph indicates a highest measured voltage of 14.2 Volts using the maximum power point tracker. As seen in Figure 8, the phenomenon of battery current charging from morning to evening is observed to be 5 amperes. This demonstrates that the maximum power point tracker operates effectively in identifying the peak power point.

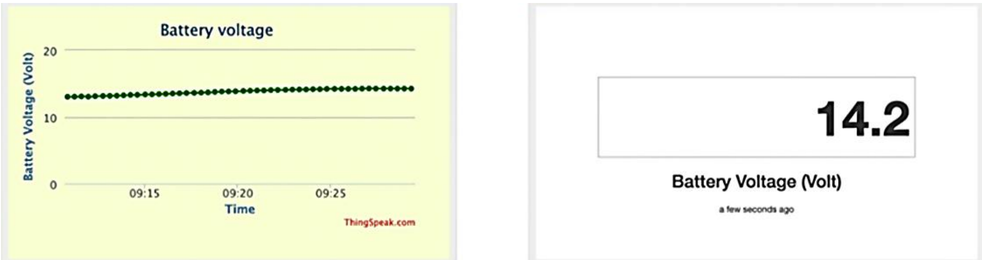

Figure 7. Battery voltage measurement graph

Figure 8. Battery charging current measurement graph

3.2. Performance load of dual energy dryer system

Increasing the intensity of solar radiation on the prototype system and monitoring it maximum power point can enhance the output power of the solar panel system, which is integrated with a microcontroller and the IoT. Figure 9 illustrates that the use of a maximum power point tracker significantly impacts the performance of the load device, as demonstrated by the double dryer system tested, as shown in the figure below. With high and medium radiation levels, the performance of the dual-energy dryer system equipped with a maximum power point tracker was investigated. Figure 9 illustrates the observed power output measurements of the solar panel system. The module's power measurement determines the maximum power throughout the day. The maximum power point tracker maintains the load at its maximum power point.

Figure 10 illustrates the results of measuring the humidity reduction during the drying system test, highlighting the primary effectiveness of using the maximum power point tracker. Figure 11 illustrates the maximum power point tracking function enabled by constant temperature control, resulting from the light intensity design parameters and the characteristics of the dual energy drying system. Figure 12 illustrates the highest light intensity measured by the dual-energy dryer system, showing the rate of increase in maximum light intensity and the measurement results obtained during testing of the device. The increase in light intensity on the panel will correspond to an increase in charging power on the battery.

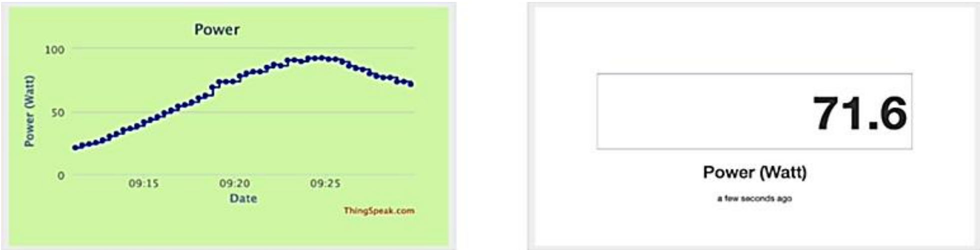

Figure 9. Measuring battery power output on a solar panel system

Figure 10. Humidity measurement of the solar panel system

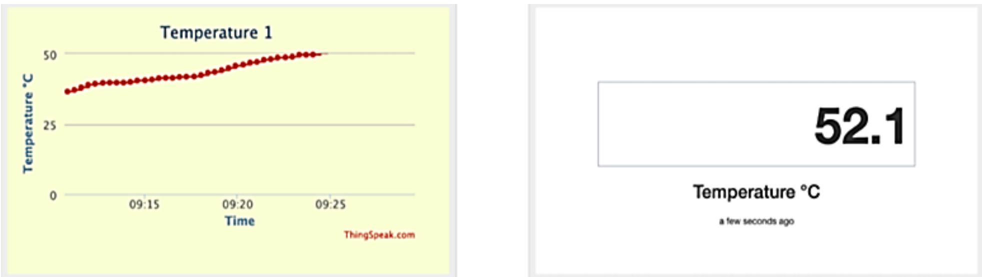

Figure 11. Temperature measurement of the solar panel system

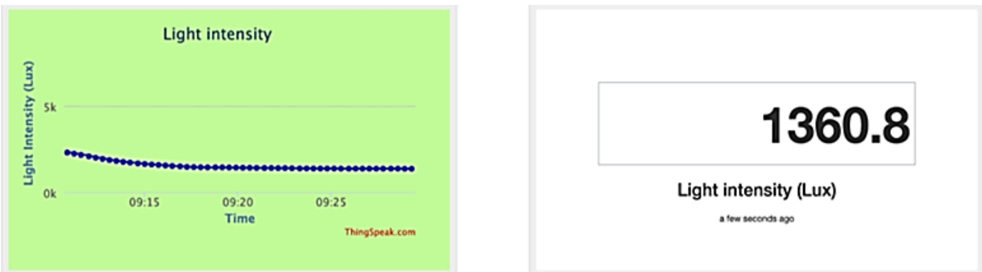

Figure 12. Measurement of light intensity

4. CONCLUSION

The proposed project demonstrates how to dry Moringa leaves promptly after harvesting with minimal effort. With the same ideas and perspectives in mind, this model offers a clear idea of how the system can be implemented at scale. We have also shown how to measure and control all aspects of the Moringa leaf to achieve accurate and effective results. The proposed system is portable and user-friendly. It does not require prior work experience, as everything works automatically, except for the moisture content measurement, which still utilizes a non-prototype measuring device. This system is ideal for small and medium-sized farmers who lack access to high-tech and expensive dryers. Farmers do not have to work because they do not have to spread Moringa leaves on drying racks on paved paths to dry in the sun. With this system, the drying process is completed in a few hours. Considering the current temperature, the solar panel performs well. It can reach up to 10 V with a boost converter, and its performance extends to voltages of up to 30 V DC at a current of 1 amp. All the components used are very cheap and readily available, so the acquisition and operating costs of the proposed system are minimal. The developed system can be used for dry grains, such as coffee beans, wheat, rice, lentils, millet, corn, and other grains, as well as leaves. The system also functions as a power bank, storing electrical energy to light homes. After the drying process is complete, the energy stored in the battery can be used to power a home or garden light, serving as an energy source.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SMJ], upon reasonable request.

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