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Development of an Internet of Things (IoT) System for Real-Time Monitoring and Control of Moringa Powder Processing.

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Abstract

Moringa leaves are a widely recognized food plant in Indonesia due to their nutritional content and health benefits; however, the production of moringa leaf powder still faces challenges due to limited human resources and time-consuming manual processes. This study aims to design and implement an IoT-based monitoring and control system to automate moringa leaf powder production. The system was developed using the waterfall method, including requirements analysis, system design, implementation, testing, and evaluation. It integrates a NodeMCU microcontroller with a DHT-11 sensor for temperature and humidity, an ultrasonic sensor, a load cell sensor, an MG996 servo motor, a box heater, a blender, and an adapter, and is connected to Firebase and an Android application for real-time monitoring and control. Performance testing at drying temperatures of 30°C, 32°C, and 35°C showed processing times of 22.73, 54.16, and 98.80 minutes, respectively, with humidity maintained between 77.94%–82.79%, coarse powder weights of 18.60–170.59 g, and fine powder weights of 38.00–44.64 g. The results indicate that the system can accurately control key parameters and monitor quality in real-time, supporting efficient and automated moringa leaf powder production. Therefore, this IoT-based system is effective in increasing productivity, maintaining product quality, and has potential for further development toward fully automated processes and more advanced data-driven control.

Keywords— *Moringa leaf powder, IoT-based system, NodeMCU, real-time monitoring, automated production, temperature and humidity control, Firebase, Android application.*

1. Introduction

Internet of Things (IoT) technology has been widely used to support daily work through more efficient and integrated systems. One example of previous research is the development of an IoT system that monitors water quality using Arduino Mega 2500 as a microcontroller and three sensors, namely a Grayscale Sensor (DFR0022), a Color Sensor (TSC34725), and a Digital Pressure Sensor (SMC PSE574). Data from the sensors can be monitored directly, stored in a PostgreSQL database, and accessed remotely via the Grafana web, which also allows users to download monitoring results.(Hong et al., 2022) Another similar study was conducted on a hazardous gas detection system in smart kitchens using DHT22 temperature sensors(Kumar et al., 2024). In addition to water and smoke quality monitoring, IoT technology is also widely applied in the agricultural sector. One example is the application of the smart garden concept, designed to support farming activities by monitoring room temperature and soil moisture, while automating the fertilization and watering processes. (El Mezouari et al., 2022)

Moringa (Moringa oleifera) is one of the most widely known food crops in Indonesia and is often referred to as the “Miracle Tree” due to its many health benefits. Various studies, including international ones, have proven the effectiveness of moringa in helping to prevent and treat various diseases. Moringa leaves that have been processed into powder can be developed into a variety of products, such as tea, herbal medicine, and face masks. The cytokinin content in moringa, which is a natural hormone that induces cell division, growth, and aging, plays a role in slowing down the aging process and rejuvenating the skin. In addition, moringa leaf powder also has significant potential in preventing metabolic diseases and several infections because it contains nutrients and therapeutic elements that are anti-inflammatory, antibiotic, and capable of strengthening the immune system. (El Mezouari et al., 2022)

Research on moringa leaf powder is still relatively new and rarely conducted, particularly in the use of technology in the production process. Most existing studies focus on nutritional content, health benefits, and the potential for developing processed products, while technology-oriented research remains very limited. One example is the study on moringa powder suitability detection using a mobile application with the CNN ensemble transfer learning method, which can assess product quality based on categories such as suitable for consumption, unsuitable due to contamination by small insects like Lesioderma serricome, unsuitable due to improper texture, or unsuitable due to color changes(Ramadhani et al., 2024). Although this study contributes to quality control, the main challenge still lies in the production process, which is currently carried out manually through a lengthy series of steps—starting from leaf collection, separation from stems, washing, drying, grinding, filtering, to packaging—that can take several days and require a workforce of around 5–10 people.

Based on the analysis of previous IoT research, most technology-based developments also remain limited to one production stage, such as the IoT drying system by I Wayan Sudiarsa et al. (2023), which focuses only on temperature and humidity monitoring, and the IoT grinding system by Ekkawit Wangkanklang and Yoshikazu Koike (2021), which uses sound signal processing to monitor grinding progress. Furthermore, no existing research has explored the development of an IoT filtering system. Therefore, this paper introduces a comprehensive IoT system integrating three stages of production—drying, grinding, and filtering—representing a significant advancement in process automation, real-time monitoring, and production efficiency for large-scale moringa powder processing.(Wangkanklang & Koike, 2021)(Sudiarsa et al., 2023)

In addition, the demand for moringa powder in Indonesia continues to rise in line with the increasingly widespread use of this plant across various sectors, including food, herbal medicine, and beauty products. This condition highlights the need for technological innovation to support a more effective and efficient production process. One potential approach is the implementation of an Internet of Things (IoT) system for real-time monitoring and control of the moringa powder production process. The system is designed not only to simplify key production stages—particularly drying, grinding, and filtering—but also to enable automatic and integrated production data recording. Through IoT integration, production data such as the weight of the resulting powder can be monitored and recorded in real time, thereby increasing work efficiency, reducing dependence on manual labor, and improving accuracy, transparency, and quality control in large-scale moringa powder production.

The novelty of this research lies in the development of a fully integrated IoT-based moringa powder production system that connects all stages of processing—from leaf drying to the production of both fine and coarse moringa powder—within a single automated and remotely monitored platform. Unlike previous IoT studies in agriculture or food processing that mainly focus on limited functions such as environmental monitoring (e.g., temperature, humidity) or single-stage automation (e.g., watering or fertilizing), this study introduces a comprehensive end-to-end solution. The proposed system is capable of monitoring six critical parameters, including the moringa content height in the main storage, temperature in the first storage, humidity in the main storage, total weight, as well as the levels of both coarse and fine powder produced. Furthermore, it features an integrated control mechanism via a mobile application called “Kelor App”, which allows users to manage three essential operational stages: opening the valve for grinding, opening the valve for powder transfer, and initiating the filtering process. Another innovative aspect of the system is its ability to distinguish between coarse and fine powder outputs—where the coarse powder can be used as moringa tea or reprocessed, while the fine powder serves as raw material for medicine or moringa flour. Thus, this research presents a technological breakthrough in moringa powder production, offering precise data monitoring, enhanced automation, reduced manual labor dependency, and improved production efficiency and product consistency on a larger scale.

2. Method

The proposed system is designed to monitor several important parameters in the moringa powder processing, including temperature, height, and the weight of coarse and fine powder. To support these functions, a NodeMCU microcontroller is used as the control center, a DHT11 sensor to measure the temperature in the container, an ultrasonic sensor to detect the volume or height of the container's contents, and a load cell sensor (1 kg capacity) to weigh the powder in both coarse and fine conditions. On the software side, this system was developed using Arduino IDE as the programming platform, Firebase Realtime Database for data storage and synchronization, and an Android application as a user interface to monitor and control the process in real-time.

2.1 System Architecture

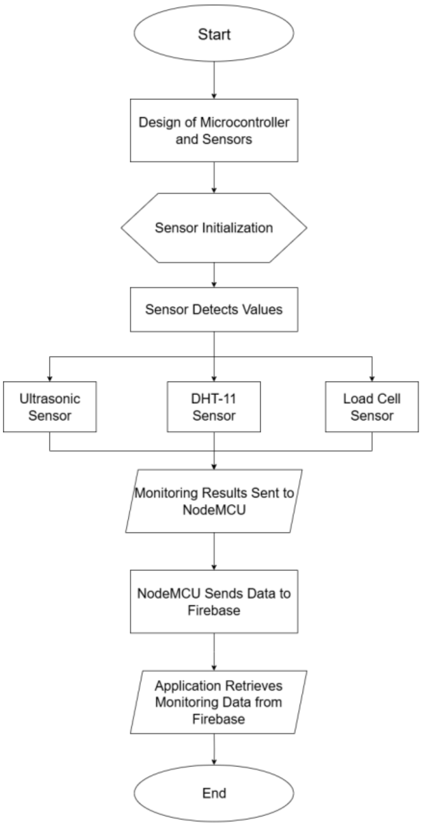


Figure 1. Monitoring Flowchart

Figure 2. Control and Notification Flowchart

Based on **Figure 1**, the workflow of the moringa powder monitoring system begins with the design stage of the microcontroller and sensors as the main components of the system. After the hardware is designed, each sensor is given an initial value or initialization to ensure that it functions according to the configuration. In the next stage, each sensor performs detection according to predetermined parameters, namely the ultrasonic sensor to measure the distance or volume of the container, the DHT11 sensor to monitor the temperature, and the load cell sensor to weigh the weight of the moringa powder, both coarse and fine. The monitoring data from all sensors is then processed by the NodeMCU microcontroller and sent in real-time to Firebase as a cloud-based storage database. Through this integration, data can be accessed, stored, and further utilized for efficient monitoring and production control purposes.

Based on **Figure 2**, the flowchart shows the control system for the moringa powder system, which begins with the design stage of the relay and sensor, which function as the main control components. After that, the sensor detects distance and weight parameters, and the readings are forwarded to the NodeMCU microcontroller to be sent and stored on Firebase in real time. In terms of temperature control, threshold-based control logic is applied. If the detected temperature exceeds 35°C, the system automatically turns off the heating relay to prevent overheating, while the servo motor remains on to allow air circulation or heat dissipation. Conversely, if the temperature is in the range of 30–35°C, the heating relay will be activated (on) to maintain the temperature within the optimal range, while the servo motor is closed (off) to keep the heat inside the container. With this mechanism, the system is able to maintain temperature stability in the moringa powder processing, so that product quality is guaranteed while reducing the need for manual intervention.

2.2 System Design

2.2.1 Mikrokontroler NodeMCU

The microcontroller used, NodeMcu in **Figure 3**, is an open-source IoT platform and development kit to assist programmers in creating IoT product prototypes or using sketches with the Arduino IDE. This study uses two NodeMCUs, where the first NodeMCU is for sensor monitoring and the second NodeMCU is for controlling (Satriadi et al., 2019).

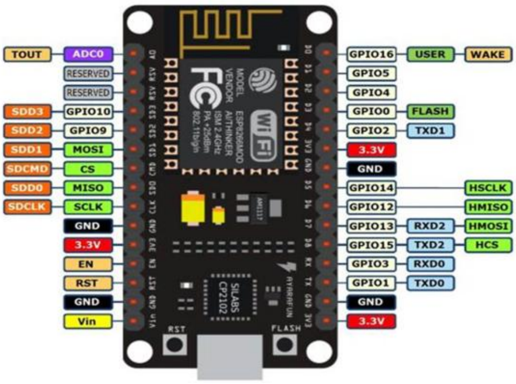


Figure 3. NodeMCU

2.2.2 DHT 11 Sensor

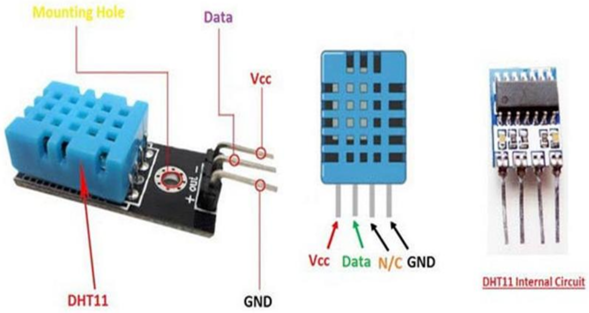


Figure 4. DHT-11

The DHT-11 sensor **Figure 4** is a device for detecting temperature and humidity, whose measurements are converted into digital signals so that they can be read directly by electronic devices without the need for a signal conditioner or analog-to-digital converter (ADC). This sensor uses digital-collecting technology and a calibrated humidity sensor, making it stable and reliable when in use. The DHT-11 connects to an 8-bit microcontroller and works as a single chip that produces digital data with fairly high accuracy, namely 14 bits for temperature and 12 bits for humidity. Its specifications include an operating voltage of 5 V, a temperature measurement range of 0–50 °C with an error margin of ±2 °C, and a humidity range of 20–90% RH with an error tolerance of ±5% RH. With a digital signal output, this sensor is simple, practical, and easy to integrate into various systems. (Audrey et al., 2021)

2.2.3 Ultrasonic Sensor

The ultrasonic sensor shown in **Figure 5** works by utilizing the principle of sound wave reflection to detect the presence of objects in front of it, with an operating frequency above sound waves, namely between 20 kHz and 2 MHz (Finamore et al., 2021). This sensor consists of two main parts: a transmitter and a receiver, each of which uses a piezoelectric crystal connected to a vibrating mechanism in the form of a diaphragm that resonates with alternating voltage. One example of a commonly used ultrasonic sensor is the HCSR-04, which has dimensions of 24 mm x 20 mm x 17 mm, an average current consumption of 30 mA with a maximum of 50 mA, a detection range of 3 cm to 3 meters, and is capable of recognizing objects with a diameter of 3 cm from a distance of more than 1 meter (Saputra & Maneetham, 2025).

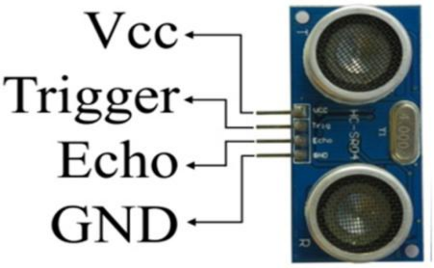


Figure 5. Ultrasonic

2.2.4 Load Cell Sensor

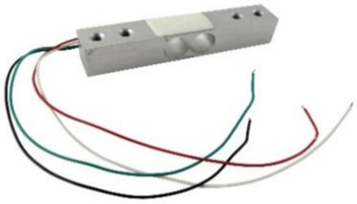


Figure 6. Loadcell Sensor

The load cell in **Figure 6** functions as a sensor to measure the weight or pressure of a load based on the principle of voltage change due to mechanical deformation (strain). This sensor is commonly used in digital scales and weighbridges (Kakade et al., 2022). It has four main wires: red (voltage input), black (ground), green (positive output), and white (negative output/ground output). Its specifications include a maximum capacity of 1 kg, operating voltage of 5–10 VDC/VAC, compact and practical size, low input/output resistance, and a non-linearity of 0.05%.

2.2.5 Servo Motor

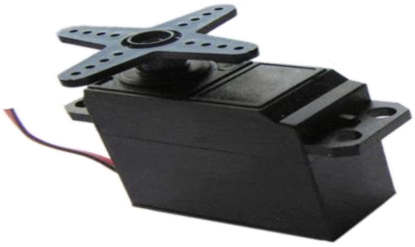


Figure 7. Servo Motor MG996 1800

The servo motor in **Figure 7** is a rotary actuator that uses a closed-loop control system (servo) to precisely regulate and maintain the angular position of the output shaft. Its main components include a DC motor, gears, control circuitry, and a potentiometer. The gears function to reduce speed and increase torque, while the potentiometer detects the shaft's position. The closed-loop system enables automatic position correction when the shaft has not yet reached the desired position. There are two types of servo motors: the Standard 180° type, which rotates bidirectionally up to 180°, and the Continuous type, which can rotate continuously without angular limits. The advantages of servo motors include: no vibration during operation, power proportional to size, current consumption according to load, accuracy that can be improved by replacing the encoder, and quiet operation at high speeds.(Tung et al., 2022).

2.2.6 Relay

Figure 8. 1-Channel Relay Module

The 1-channel relay module in **Figure 8** is an electronic switch device that operates based on a control signal, allowing the switching of both AC (alternating current) and DC (direct current) electrical flows. This relay is used to control devices with higher voltage or current than the control source. The module has the following specifications: output up to 240V/2A, operating voltage of 5V, standby current of 0 mA, input voltage of 0–1.5V, operating current of 2 mA, and a weight of 13 grams (Parab & Prajapati, 2019).

2.2.7 Motor Gear Box

Figure 9. Motor Gear Box

The DC Gearbox Motor **Figure 9** is an electronic device that functions as a rotary actuator by converting electrical energy into mechanical energy. Its working principle is similar to that of electric motors found in household appliances such as fans or mixers (Verstraten et al., 2015). This motor consists of several main components, including the field poles—which consist of north and south poles where magnetic field lines flow—the armature (a cylindrical dynamo) connected to the driving current to rotate the load, and the commutator, which serves as the current bridge between the dynamo and the power source.

2.2.8 Design System Prototype

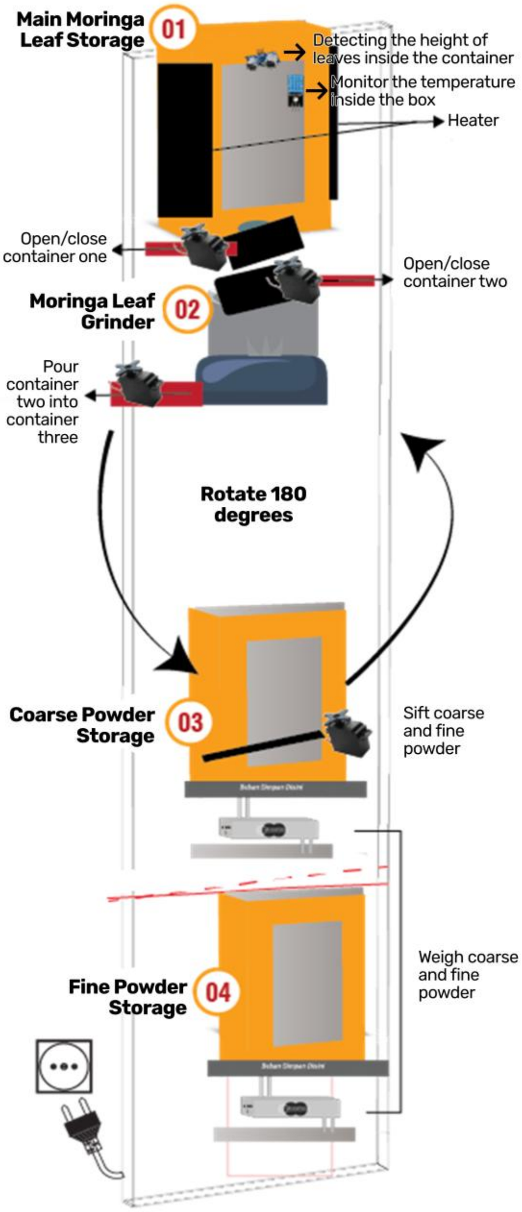
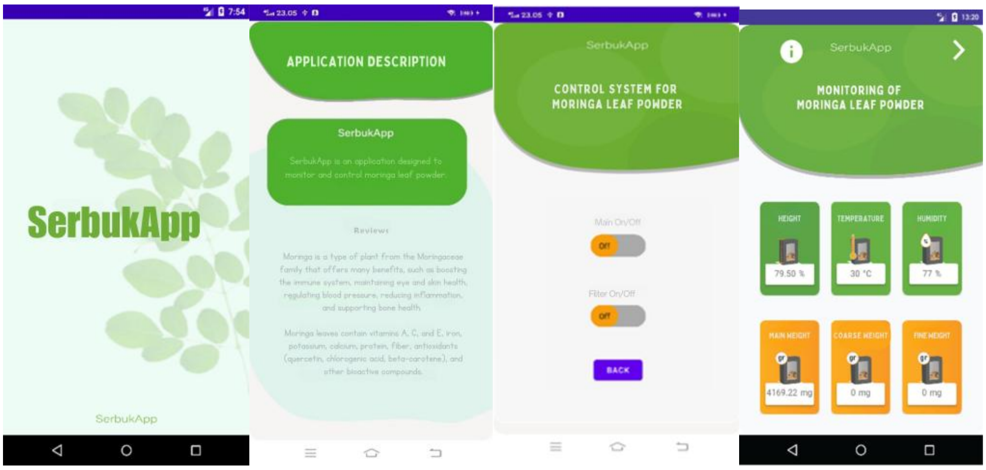


Figure 10. Design System Prototype

The **Figure 11** illustrates the flow of the IoT-based automated moringa leaf powder production system. The process begins with the storage of moringa leaves, where sensors measure the height of the leaves in the container and monitor the temperature and humidity inside the drying box with the help of a heater. Next, the moringa leaves are transferred to a moringa grinder, where the leaves are poured into a grinding container to be crushed into coarse powder. The coarse powder is then transferred to coarse powder storage, where the powder is filtered to separate the fine particles. Finally, the fine powder is stored in the fine powder storage, while being accurately weighed using a load cell sensor. The entire process can be monitored and controlled in real-time through an IoT-based system, making moringa leaf powder production more efficient, automated, and quality-controlled.

2.2.9 System Prototype Design



SerbukApp is an application designed to monitor and control moringa leaf powder.

Moringa is a type of plant from the Moringaceae family that offers many benefits, such as boosting the immune system, maintaining eye and skin health, regulating blood pressure, reducing inflammation, and supporting bone health.

Moringa leaves contain vitamins A, C, and E, iron, potassium, calcium, protein, fiber, antioxidants (quercetin, chlorogenic acid, beta-carotene), and other bioactive compounds.

HEIGHT: 79.50 %
TEMPERATURE: 30 °C
HUMIDITY: 77 %
MAIN WEIGHT: 4169.22 mg
COARSE WEIGHT: 0 mg
FINE WEIGHT: 0 mg

Figure 12. Visualization in SerbukApp

In the SerbukApp application shown in **Figure 11**, there are monitoring, controlling, and notification features. The monitoring feature functions to display the fill level, temperature, and weight within the container. The controlling feature is used to manage or operate the system being developed, while the notification feature provides users with information regarding the system's processes.

2.2.10 Mechanical Design

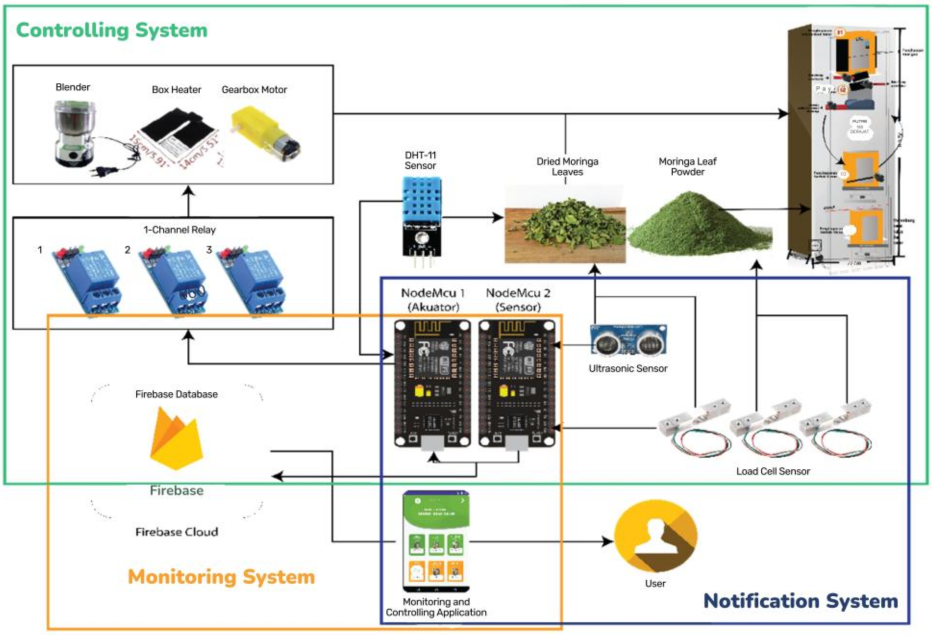


Figure 13. Mechanical Design

The system architecture diagram in **Figure 12** provides a comprehensive overview of the IoT-based automation workflow for moringa powder production, which integrates control, monitoring, and notification subsystems. The selection of each component is based on scientific and practical considerations to ensure the system operates efficiently, reliably, and accurately. The NodeMCU ESP8266 was chosen as the central controller because it has a built-in Wi-Fi module, low power consumption, and supports real-time data communication to the cloud. The DHT11 sensor is used to measure temperature and humidity with sufficient accuracy to maintain stable drying conditions, while the ultrasonic sensor is selected to measure the container's fill height in a non-contact manner, ensuring hygiene and minimizing measurement errors. The load cell sensor provides precise weight measurements of both coarse and fine moringa powder, supporting quality control and production tracking. Relays, gearbox motors, servos, and a blender serve as actuators to control valves, heaters, and mechanical processing units for drying, grinding, and filtering stages. On the software side, the Arduino IDE is used for programming due to its flexibility and compatibility, while the Firebase Realtime Database enables real-time cloud-based data storage and synchronization. The Android-based “Kelor App” acts as an interactive user interface for remote monitoring and control. This component selection ensures the system functions as an integrated, efficient, and data-driven automation solution for large-scale moringa powder production with minimal manual intervention.

2.2.11 Software

The structured testing design of the IoT-based moringa powder production system is presented in Table 1. Each trial used 4100 mg (4.1 g) of dried moringa leaves with 4–5 repetitions for each production stage, including drying, grinding, and filtering. Each process took approximately 20–30 minutes, depending on the initial leaf volume and humidity level. All measurement data were recorded and stored in real time using Firebase Realtime Database, allowing accurate and continuous process monitoring. The system utilizes three main software tools: Arduino IDE, Android Studio, and Firebase. Arduino IDE functions as the programming and uploading environment for the microcontroller with a simple and user-friendly interface, while Android Studio is used to develop the mobile application that enables real-time system visualization and control through a smartphone.(Zimányi et al., 2018) Firebase serves as a cloud-based real-time database for data storage and synchronization, using an efficient NoSQL architecture that supports IoT and mobile applications with instant data updates across all connected devices.

Table 1. Structured Testing Design of the IoT-Based Moringa Powder Production.

Testing Aspect	Description
Processing Date	4100 mg (4,1 g) of dried moringa leaves per trial
Number of Repetitions	4-5 repetitions for each production stage (drying, grinding, filtering)
Processing Duration	20–30 minutes (depending on initial leaf volume and humidity level)
Data Storage	Real-time via Firebase Realtime Database

3. Results And Discussion

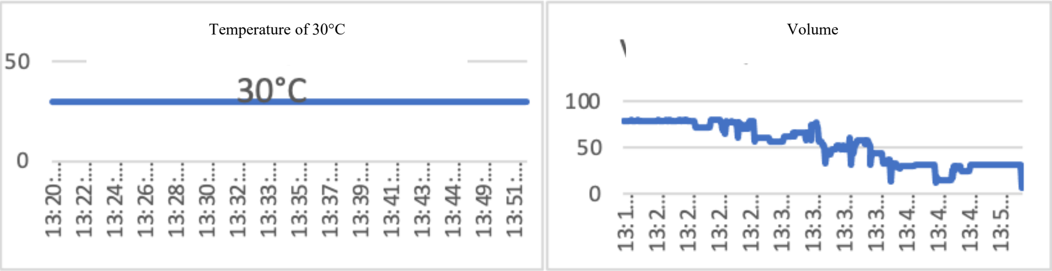
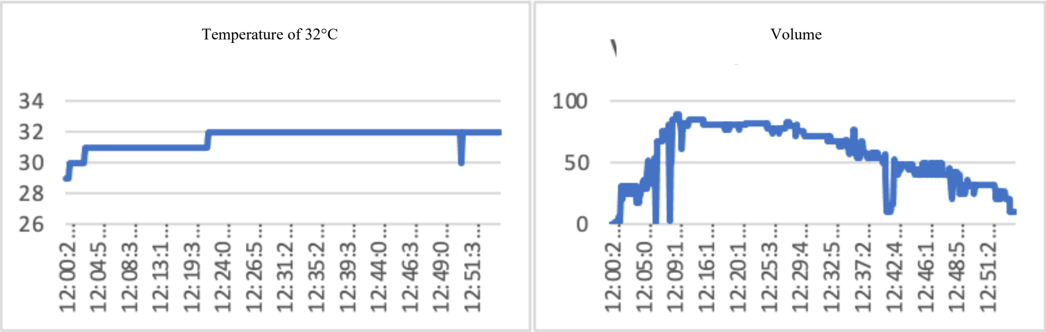


Figure 14. Sensor Results Graph at 30°C

System performance evaluation was carried out using dried moringa leaf powder samples that had been manually dried for four days (January 10–14, 2025) and processed on January 16, 2025. Once activated, the system first checks initial parameters such as temperature, humidity, and the volume of the main container. If parameters such as volume, gross weight, and fine weight are close to zero, the dried moringa leaves are placed into the storage container for processing. During testing at a room temperature of 30°C, the system was able to process the moringa leaves into powder in 1364 seconds (22.73 minutes), with a total of 25 processing cycles generating 341 monitoring data points. The resulting powder color closely resembled the original moringa leaf color, indicating that the processing did not damage the green pigment (chlorophyll), statement that drying temperature and duration affect color organoleptically.

Based on the sensor evaluation graphs, the average recorded temperature was stable at 30°C, consistent with the ambient room temperature, which required no additional heating. The ultrasonic sensor showed an average container fill level of 53.43%, with the system providing a notification if the level dropped below 10%. The humidity sensor recorded an average of 77.94%, which is close to the dry material storage standard of 80–90% as stated by the Indonesian Ministry of Health (Kemenkes RI, 2013). Loadcell 1 indicated an average weight of the main container at 2164.94 mg (216.49 grams) from an initial weight of 4169.22 mg. Loadcell 2 detected an average coarse powder weight of 1705.93 mg (170.59 grams), with a final weight of 535.74 mg. Meanwhile, Loadcell 3 recorded an average fine powder weight of 382.50 mg (38 grams), with a final result of 3566.07 mg (356.60 grams). These results indicate that the system is capable of efficiently monitoring and processing moringa leaves at a temperature of 30°C.



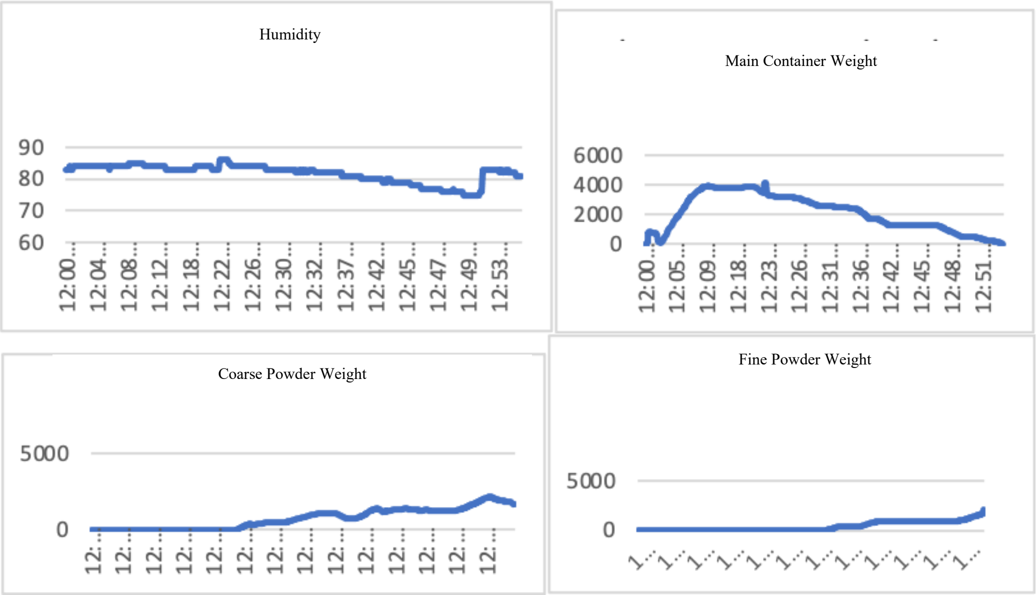
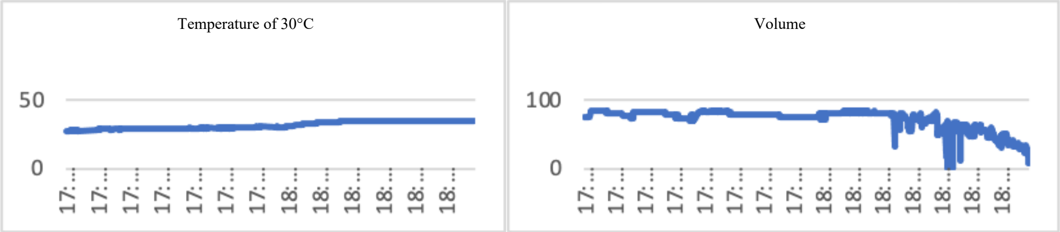


Figure 15. Sensor Results Graph at 32°C

System evaluation at a temperature of 32°C showed that the moringa leaf powder processing still functioned properly, although it required more time compared to processing at 30°C. The moringa leaves used were manually dried for four days (January 10–14, 2025) and processed on January 17, 2025. When the system was activated, an initial check was conducted on temperature, humidity, and container volume. Since the initial temperature was still at 30°C, the system waited until it rose to 32°C before beginning the process, with a waiting time of approximately 674 seconds (11.23 minutes). The total processing time reached 2066 seconds, or 34.43 minutes, across 28 processing cycles and generated 518 monitoring data points. The color of the resulting moringa powder at this temperature tended to be slightly brownish, indicating a possible effect of temperature on chlorophyll content, statement that temperature and drying duration influence color organoleptically.

The sensor graph results indicate that the average recorded temperature was 31.61°C, which is close to the target temperature of 32°C. The ultrasonic sensor recorded an average container fill level of 55.90%, and the system sends a notification to the application if the level drops below 10%. The humidity sensor showed an average of 81.78%, which complies with the dry material storage standard according to the Indonesian Ministry of Health (Kemenkes RI, 2013). The average weight in the main container, as measured by Loadcell 1, was 2087.24 mg (208.72 grams), from an initial weight of 4164.87 mg. Meanwhile, Loadcell 2 recorded an average coarse powder weight of 736.09 mg (73.60 grams), with a final weight of 1638.38 mg. For fine powder, Loadcell 3 recorded an average weight of 390.12 mg (39 grams), with a final result of 2090.00 mg or 209 grams. These results demonstrate that the system can still operate optimally at 32°C, although with slight changes in color and a longer processing duration.



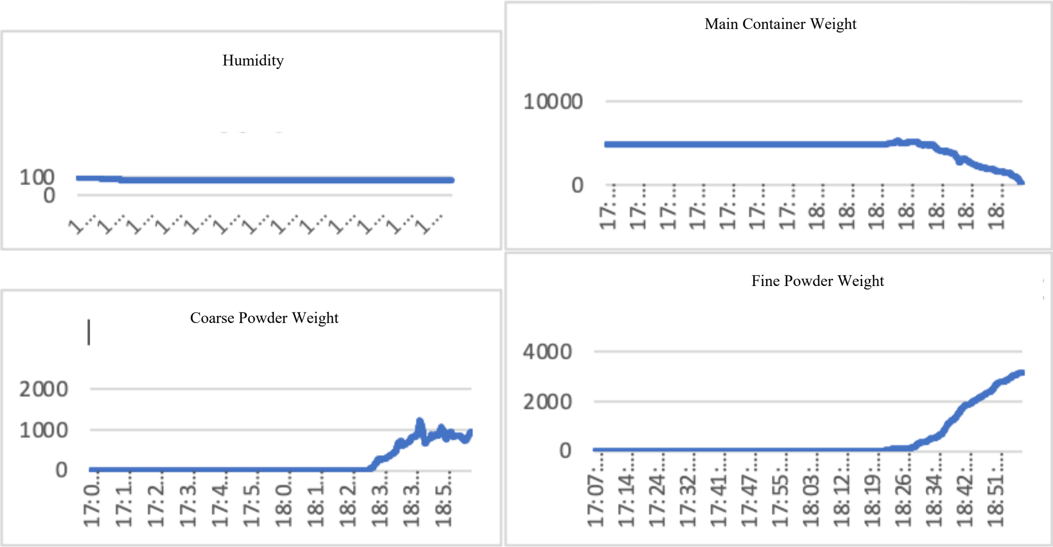


Figure 16. Sensor Results Graph at 35°C

System testing at a temperature of 35°C showed that the moringa leaf powder processing could still operate properly, although the processing time was longer compared to previous temperatures. The moringa leaves, which had been manually dried for four days (January 10–14, 2025), were processed on January 20, 2025. When the system was activated, the initial temperature was still at 30°C, requiring a waiting time of 3324 seconds (55.4 minutes) for the temperature to reach 35°C before the process could begin. The total time needed to complete 28 processing cycles was 4968 seconds, or 1 hour and 38 minutes, generating 1242 monitoring data points. The moringa powder produced at this temperature appeared slightly browner than at 32°C, indicating increased chlorophyll pigment degradation with rising temperature. statement that temperature and drying duration significantly affect the color changes of moringa leaves in terms of organoleptic quality.

Based on the sensor graph results, the average recorded temperature was 31.54°C, indicating that the system remained within tolerance before reaching its operational point. The ultrasonic sensor recorded an average fill level of 72.37%, and the system continued to send notifications if the level dropped below the threshold. The average humidity at this temperature was 82.79%, which is still in accordance with the dry material storage standard by the Indonesian Ministry of Health (Kemenkes RI, 2013). The average weight in the main container (Loadcell 1) was recorded at 4363.96 mg (436.39 grams), with an initial weight of 4914.55 mg. The average coarse powder weight (Loadcell 2) was 186.04 mg (18.60 grams), with a final weight of 951.02 mg, while the average fine powder weight (Loadcell 3) was 446.43 mg (44.64 grams), with a final result of 3165.05 mg (316.50 grams). These results indicate that the system continues to function optimally at 35°C, although color change and extended processing time remain the main challenges.

Table 2. Performance evaluation of moringa leaf powder at temperatures of 30°C, 32°C, and 35°C.

Parameter	30°C	32°C	35°C
Processing Date	January 16, 2025	January 17, 2025	January 20, 2025
Number of Processes	25	28	28
Average Humidity (%)	77,94	81,78	82,79
Main Container Weight (g)	216,49	208,72	236,32
Coarse Powder Weight (g)	170,59	73,60	18,60
Fine Powder Weight (g)	38,00	39,01	44,64

Based on the evaluation data **Table 1** of the performance evaluation of the moringa leaf powder processing system at drying temperatures of 30°C, 32°C, and 35°C. Based on the data, it can be concluded that the system performs well and is capable of accurately controlling key parameters such as temperature, humidity, and the weights of coarse and fine powder. The processing time increased significantly with rising temperature, from 22.73 minutes at 30°C to 98.80 minutes at 35°C. Humidity consistently remained within the standard range for dry material storage (approximately 78–83%), while the weights of coarse and fine powder varied but were effectively monitored. The progressively browner color of the powder at higher temperatures indicates the effect of temperature on chlorophyll pigment degradation. The results suggest that drying temperatures of 30°C, 32°C, and 35°C are optimal for producing high-quality moringa leaf powder, balancing efficient drying with the preservation of nutritional and physical quality. Overall, this IoT-based system is effective in processing and monitoring the quality of moringa leaf powder in real-time across these optimal drying temperatures.

Table 2. Comparison of Moringa Leaf Powder Production: Manual vs IoT System.

Parameter	Manual Method	IoT System
Production Stages	Drying, grinding, and filtering are done manually and separately	All stages (drying, grinding, filtering, separation of fine and coarse powder) are automated and integrated in one system
Drying Duration	5–7 hours depending on temperature (35°C, 50°C, 65°C)	Automated drying process completed in 20–30 minutes, depending on leaf volume and humidity level Stable at **30°C, 32°C, 35°C.**
Average Humidity	Not specifically stated	77.94%, aligned with the dry material storage standard (80–90%, Indonesian Ministry of Health, 2013)
Parameter Monitoring	Not available; process relies on manual observation	Real-time monitoring of six parameters: content height, temperature, humidity, total weight, coarse powder weight, and fine powder weight
Number of Production Cycles	Not measured (manual process)	25 automatic cycles with 341 recorded monitoring data points
Labor Requirement	5–10 workers for full manual stages	1 operator using the Kelor App for full control
Sensor / Measurement Accuracy	No automatic measurement	Temperature sensor ±1°C, humidity sensor ±2% RH, loadcell accuracy 95–97%
Powder Output	3–4 days are required to dry the moringa leaves until they are ready for grinding, depending on weather conditions and humidity levels, to produce 356.6 grams of moringa leaf powder manually.	Average recorded: total container weight 216.49 g, coarse powder 170.59 g, fine powder 38 g, total final weight 356.6 g
Main Advantages	Maintains vitamin C and natural flavor	Fast, efficient, automated, data-driven, and preserves natural green color

A clear comparison between the manual and IoT-based moringa leaf powder production methods is presented in **Table 2**. The manual method requires separate handling of drying, grinding, and filtering stages, taking approximately 3–4 days to produce 356.6 g of powder and involving 5–10 workers. In contrast, the IoT system automates all processing stages in one integrated platform, completing drying in 20–30 minutes with real-time monitoring of six key parameters. It records 25 production cycles and 341 data points, ensuring higher accuracy (95–97%) while reducing labor to just one operator. This system enhances efficiency, consistency, and product quality by maintaining stable temperature and humidity, making the process faster and more reliable than traditional methods.

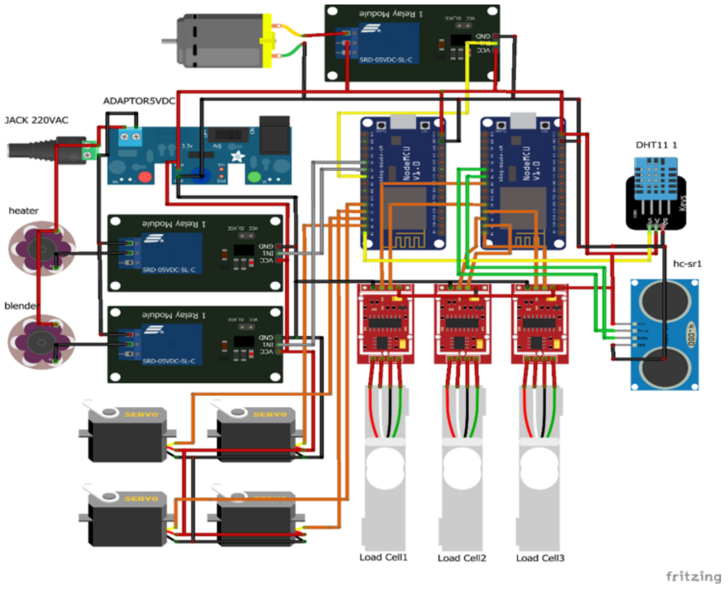


Figure 17. System Hardware Components

In the designed system, two NodeMCU units are used as the main control centers as well as connectors between sensors and actuators. These NodeMCUs come equipped with built-in WiFi, facilitating data communication and automatic system integration. Several sensors are connected, including an ultrasonic sensor, which functions to detect the distance or material level in the main moringa leaf container through four main pins (VCC, GND, Trigger, and Echo). This sensor operates by emitting ultrasonic waves via the Trigger pin and receiving the echoes through the Echo pin, allowing it to calculate the distance to an object. Additionally, a DHT11 sensor is used to measure the temperature and humidity inside the storage container. This sensor has three pins: VCC, Data, and GND, and provides digital data directly without requiring analog conversion. Meanwhile, load cell sensors are used as weighing devices to measure the weight of the main container as well as the processed moringa leaf powder, both coarse and fine. Each load cell is connected to the NodeMCU via four pins (VCC, GND, Data, and Clock) with different configurations according to the sensor order, enabling all weighing results to be monitored automatically and accurately.

In addition to sensors, this system is also equipped with actuators in the form of relays and servo motors controlled by the NodeMCU. There are three single-channel relays used, each configured to automatically control electrical devices such as the box heater, blender, and DC gearbox motor according to commands from the microcontroller. Meanwhile, servo motors are used to regulate mechanical mechanisms, such as opening and closing valves on the main container, rotating the blender up to 180 degrees, and filtering the moringa leaf powder according to the specified timing. The system contains four servo motors, each connected to the NodeMCU via data, VCC, and GND pins with different configurations. With the integration of the NodeMCU, sensors, relays, and servo motors, the entire process—from measurement and device control to material processing—can be carried out automatically, accurately, hygienically, and efficiently without requiring much manual intervention.

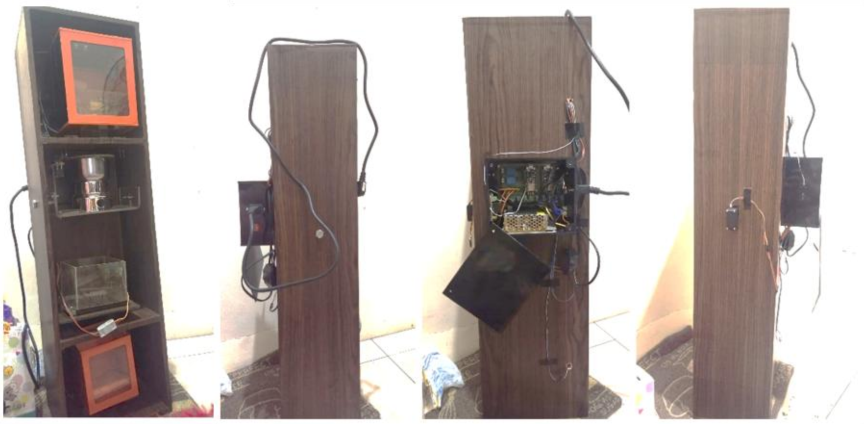


Figure 18. Electronic Design Results

The developed system utilizes two NodeMCU ESP8266 microcontrollers along with three main types of sensors: an ultrasonic sensor to measure distance, a DHT-11 sensor to monitor temperature, and a load cell sensor to detect weight. This hardware is designed as an integrated automatic system used in the processing of moringa leaf powder. The system consists of four containers, each with its own function and components. The first container serves as the main storage for dried moringa leaves and is equipped with two heaters, a DHT-11 sensor, an ultrasonic sensor, and a load cell. The second container functions as a grinder, featuring an automatic open-close mechanism driven by a servo motor, which transfers material from the first container to the sieve.

The third container serves as a coarse powder collection and sieving chamber, equipped with a load cell sensor to measure the weight of the coarse powder before it proceeds to the final stage. The fourth container is used to store the fine powder and is also equipped with a load cell sensor. Each container has different sizes and supporting equipment according to its function. The first container uses a metal box measuring 17x17x15 cm, the second container is a blender sized 170x105 mm, the third container is an acrylic box measuring 13x13x10 cm, and the fourth container is again a metal box with dimensions of 12x12x14 cm..

4. Conclusions

The development of an Internet of Things (IoT) system for real-time monitoring and control of moringa leaf powder production has been successfully implemented. The system integrates a NodeMCU ESP8266 microcontroller with an ultrasonic sensor, DHT-11 sensor, and load cell, as well as supporting devices such as a servo motor, box heater, gearbox motor, and blender. Testing at drying temperatures of 30°C, 32°C, and 35°C demonstrated that the system can adjust the process according to target temperatures, maintain humidity within the ideal range (80–90%), and monitor material weight and height in real-time. This system supports efficient automated processing, preserves the nutritional and physical quality of moringa powder, and provides notifications when the main container level falls below the minimum threshold.

The scientific contribution of this study lies in the application of an IoT-based system for real-time quality control in moringa leaf powder production, improving process efficiency, product consistency, and data-driven decision-making. For future development, the system can be enhanced by integrating a DS18B20 temperature sensor for higher accuracy, implementing Machine Learning (ML) for automatic temperature and humidity control, extending the system from drying to fully automated powder production, and improving the main container design for more even heat distribution. With these improvements, the system has the potential to produce ready-to-use moringa powder efficiently and adaptively, while opening opportunities for industrial and commercial applications.

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