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DEVELOPMENT OF A SMART IOT-BASED MONITORING SYSTEM FOR FERTIGATION AND SEED WEIGHT DETECTION IN SACHA INCHI

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Abstract— *This research focuses on designing a fertilization monitoring system based on the Internet of Things (IoT) and detecting the weight of Sacha Inchi plant seeds. The two tools are integrated with IoT platforms, enabling remote monitoring and control via the Simosachi app. Test results indicate that the system provides accurate data on soil and plant conditions, allowing farmers to make informed decisions on fertilization and irrigation. The seed weight detection tool also functions well, with a minor error margin still within acceptable limits. With improved monitoring and control of the fertilization process, as well as accurate monitoring of crop yields, the system is expected to help farmers achieve more optimal harvests. The seed weight detection tool achieved an accuracy of 97.94%, surpassing similar prior systems in terms of real-time data integration and multi-parameter monitoring. Future research may focus on enhancing the accuracy of the seed weight detection tool and developing advanced fertigation control algorithms.*

Keywords*: fertilization, Internet of Things (IoT), monitoring, sacha inchi, sensors*

Intisari— *Penelitian ini berfokus pada perancangan sistem monitoring fertigasi berbasis Internet of Things (IoT) dan alat pendeteksi bobot biji tanaman Sacha Inchi. Kedua alat ini terintegrasi dengan platform IoT, memungkinkan pemantauan dan pengendalian jarak jauh melalui aplikasi Simosachi. Hasil pengujian menunjukkan bahwa sistem ini mampu memberikan data yang akurat terkait kondisi tanah dan tanaman, sehingga petani dapat mengambil keputusan yang tepat dalam hal pemupukan dan penyiraman. Alat pendeteksi bobot biji juga berfungsi dengan baik, dengan tingkat kesalahan yang masih berada dalam batas yang dapat diterima. Dengan adanya pemantauan dan pengendalian yang lebih baik terhadap proses fertigasi, serta pemantauan hasil panen yang lebih akurat, sistem ini diharapkan dapat membantu petani mencapai hasil panen yang lebih optimal. Alat pendeteksi bobot biji mencapai tingkat akurasi sebesar 97,94%, melampaui sistem serupa sebelumnya dalam hal integrasi data secara real-time dan pemantauan multi-parameter. Penelitian selanjutnya dapat difokuskan pada peningkatan akurasi alat pendeteksi bobot biji serta pengembangan algoritma kontrol fertigasi yang lebih canggih.*

Kata Kunci*: fertigasi, Internet of Things (IoT), monitoring, sacha inchi, sensor.*

INTRODUCTION

Sacha Inchi (Plukenetia volubilis L.) is a high-value crop recognized as a rich source of high-quality vegetable oil, containing exceptionally high levels of essential fatty acids, namely Omega-3 (±45.2%), Omega-6 (±36.8%), Omega-9 (±9.6%), and saturated fats (±7.7%). These nutritional characteristics position Sacha Inchi as a strategic commodity with considerable potential as a raw material for the functional food and pharmaceutical industries[1].

In Indonesia, interest in cultivating Sacha Inchi has been steadily increasing in line with greater public awareness of healthy lifestyles and the growing global demand for natural-based products[2]. However, its development still faces several technical challenges, including genetic

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variability and low seed viability, susceptibility to pests and diseases, and specific environmental requirements such as soil pH 5.5–7.0, moisture levels of 60–70%, and temperatures between 25–30°C [3]. Agronomic research conducted in Bogor indicates that Sacha Inchi cultivation achieves higher productivity in open fields compared to agroforestry systems, although oil quality remains relatively stable across different conditions [4].

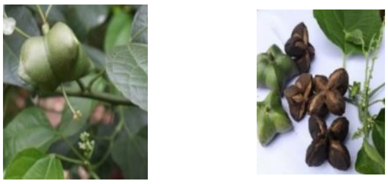
From a socio-economic perspective, the development of the Sacha Inchi agribusiness ecosystem in Purwakarta through the One Village One CEO program successfully increased farmers' income by 27%, created 80 new jobs, and reclaimed 28 hectares of idle land. These findings demonstrate that Sacha Inchi development not only contributes to food and nutrition security but also delivers significant impact on community economic empowerment [4].

In addition to technical aspects, the development of Sacha Inchi in Indonesia is also influenced by socio-economic factors, including farmers' perceptions, market access, and technology adoption. Recent studies have shown that the combination of Sacha Inchi seed-shell waste as fertilizer treatment and farmers' perception analysis using **PLS-SEM** and **ANFIS** methods can establish a more sustainable prediction model for Sacha Inchi development. The results indicated that economic factors (50.66%) were slightly more dominant than social factors (49.33%) in influencing farmers' decisions to cultivate this crop, while the use of seed-shell waste as organic fertilizer significantly increased productivity, yielding up to 285 g per fruit [5][5].

Source: (Research Results, 2025)
Figure 1. Sacha Inchi Plant Tree (source: personal documentation)

This plant contains a wide range of nutrients beneficial to human health, including Omega-3 fatty acids (45.2%), Omega-6 (36.8%), Omega-9 (9.6%), and saturated fats (7.7%). The abundance of these essential fatty acids positions Sacha Inchi as a strategic resource with substantial potential as a raw material for the food and pharmaceutical industries. Plukenetia Volubilis L., an oil-rich yet underutilized plant, possesses an exceptional lipid composition and has great potential for further domestication, malnutrition alleviation, and integration into sustainable food production systems [6]

In Indonesia, the cultivation of sacha inchi is still relatively limited, even though this plant has significant potential due to its high nutritional content and health benefits. The plant bears green star-shaped fruit that turns dark brown when ripe. The *sacha inchi* seeds are oval-shaped, dark brown, and are the most commonly used part. The seeds can be processed into oil, flour, or consumed directly as a snack. With the increasing public awareness of healthy lifestyles, the cultivation of *sacha inchi* in Indonesia is expected to grow significantly.



(a) (b)

Source: (Research Results, 2025)
Figure 2. (a) Unripe Sacha Inchi Fruit and (b) Ripe Sacha Inchi Fruit (source: personal documentation)

Source: (Research Results, 2025)
Figure 3. *Sacha Inchi Seeds(*(source: personal documentation)

Currently, some parties have begun cultivating *sacha inchi*, such as PT Quilla Indonesia Sejahtera. This study followed a Focus Group Discussion (FGD) aimed at collecting data and gaining insights related to the *sacha inchi* plant. One such effort involved the Srikandi women farmers group in the Cikadu area, Sindangkerta District, West Bandung Regency, which served as a community service location focused on *sacha inchi* cultivation. This group is one of the few actively cultivating *sacha inchi* and has collaborated with

Kiosagro and Quilla as post-harvest product buyers. These harvests are processed into various health and food products, leveraging the nutrient-rich potential of sacha inchi[6]Click or tap here to enter text.

Sacha inchi, also known as *Inci nut*, is a type of plant whose seeds are used in various products. The seeds can also be consumed after being fried or roasted and have a star-shaped structure with a hard, layered shell. *Sacha inchi* originates from the highland rainforest in the Amazon basin and is also referred to as *inca peanut*, *sacha peanut*, and *mountain peanut* Click or tap here to enter text. In the Focus Group Discussion (FGD), the researchers identified several challenges in the cultivation of *sacha inchi*. The plant requires specific environmental conditions, namely altitudes above 300 meters above sea level, fertile soil with good drainage, and a slightly acidic to neutral pH level. Ideally, sandy clay soil rich in organic matter serves as the best growing medium. Moreover, regular irrigation is crucial, especially during the dry season[8].

Findings from a Focus Group Discussion (FGD) conducted with the Srikandi Farmer Group in Cikadu, West Bandung Regency, revealed the need for more precise technology in Sacha Inchi cultivation. Key issues identified included limited irrigation during the dry season, difficulties in recording seed weights due to variability inFERT seed size and shape, and insufficient data to support fertilization decision-making. Furthermore, the integration of ***Artificial Intelligence (AI)*** *and* ***Internet of Things (IoT)*** in precision agriculture has significantly enhanced modern farming practices. AI-driven approaches, combined with IoT sensor networks and satellite data, have been shown to optimize crop yield prediction, soil health monitoring, and resource efficiency. For example, [7] highlights that convolutional neural networks, LSTM models, and ensemble methods can accurately predict yield fluctuations by integrating soil, weather, and remote sensing data, thus providing farmers with actionable insights for sustainable decision-making. Recent reviews highlight the potential of integrating IoT and machine learning to optimize agricultural decision-making processes [8] To address these challenges, this study developed an Internet of Things (IoT)-based automatic fertigation system integrated with a digital seed weight measurement device[9]. This system is expected to provide an end-to-end solution, from plant nutrient management to accurate, real-time yield recording. Unlike previous studies that focused on only one aspect of cultivation [9], [10], this study integrates fertigation control and harvest weight measurement into a single mobile platform (*Simosachi*), specifically designed to meet the cultivation needs of Sacha Inchi in Indonesia.

MATERIALS AND METHODS

The research method used in this study includes several stages including [10]: the stages of project planning, research, part testing, mechanical design, electrical design, software design, functional test, integration in Figure 4.

Source: (Research Results, 2025)

Figure 4. Research Methodology.

A. Data Collection

Data were collected using multiple techniques, including structured interviews, direct field observations, sensor requirement analysis, and literature review. Respondents consisted of members of the Srikandi Farmer Group in Cikadu Village, Sindangkerta District, West Bandung Regency. Field data collection was conducted over a three-month period on a Sacha Inchi plantation. The structured interview included questions such as: (1) What is your experience in cultivating Sacha Inchi? (2) What challenges do you face during irrigation and fertilization? (3) How do you currently measure seed yields? (4) What is your opinion on using automated IoT systems for cultivation?

B. System Design

The system design outlines the overall architecture of both hardware and software components, categorized into three core modules: input, process, and output. The system is cantered

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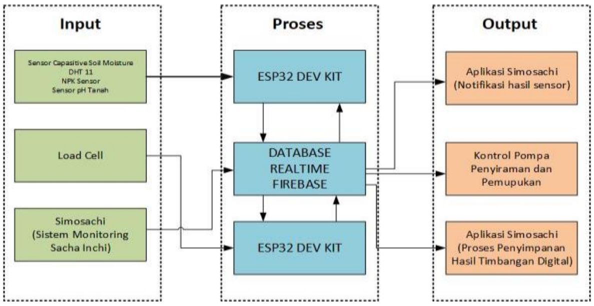
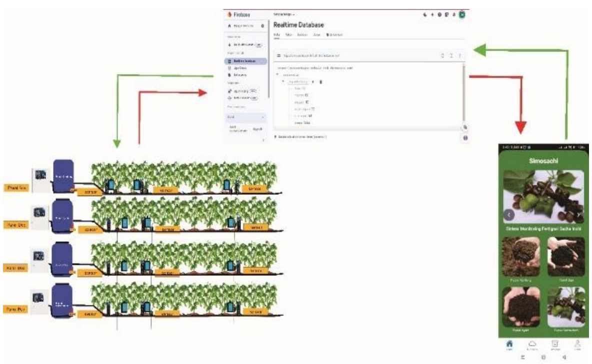
around an ESP32 microcontroller and includes various sensors for environmental monitoring and post-harvest evaluation[11]. ESP32 was selected over other microcontrollers such as Arduino Uno, ESP8266, and Raspberry Pi due to its dual-core processor, integrated Wi-Fi and Bluetooth modules, low power consumption, sufficient GPIO availability for multiple sensors, and competitive cost. This combination of features makes it well-suited for real-time IoT-based agricultural monitoring and control[12].



Source: (Research Results, 2025)
Figure 5. System Block Diagram (Source: Personal Documentation)

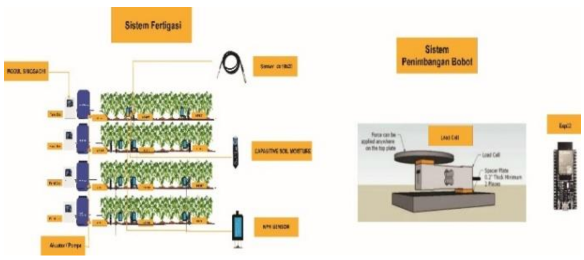
The system comprises the following stages:
a. Users log in to the Simosachi mobile application and access the monitoring module.
b. Sensor data are retrieved from the web server and processed accordingly.
c. The processed data are displayed in real time based on the selected plant.
d. For weighing, users select the seed measurement feature within the application.
e. After activating the weighing module, seeds are placed on the load cell, and parameters such as harvest month, date, and fertilizer type are entered.
f. The application computes and displays the weight, which can be saved by clicking the "Save Harvest Data" button.



Source: (Research Results, 2025)
Figure 6. Overall System Illustration (Source: Personal Documentation)

Figure 7 shows the illustration displays a comprehensive overview of the system, including the Simosachi module and integrated sensors. The module enables identification of optimal harvest periods through real-time monitoring of soil and plant parameters. Assumptions include consistent internet access for both the module and user devices; thus, network reliability is not addressed in this study.

1. Hardware: The system is controlled by an ESP32 microcontroller and is equipped with various sensors, including soil moisture, temperature (DS18B20), soil pH, NPK, and a load cell for measuring seed weight. An actuator in the form of a pump is controlled based on input data from the sensors, enabling the system to operate automatically.



Source: (Research Results, 2025)
Figure 7. Hardware Design (Source: Personal Documentation)

2. Software: The mobile application was developed using the React Native framework for the Android platform, with Firebase Realtime Database as the backend. This system enables real-time data acquisition and visualization via internet connection.

C. System Implementation

The system implementation is carried out in two main modules:
1. Automatic Fertigation Module: This system controls irrigation and fertilization processes based on sensor data. When parameters such as soil moisture or nutrient levels fall below predefined thresholds, the system automatically activates the pump for watering or fertilizing.
2. Automatic Weighing Module: A load cell sensor is used to digitally measure the weight of Sacha Inchi seeds. The measurement data is automatically sent to Firebase and displayed on the Android application.

D. Testing and Validation

Each sensor was tested in five repetitions under different environmental conditions (morning, afternoon, cloudy, rainy, and controlled indoor) to ensure consistency and repeatability. Accuracy was evaluated by comparing sensor outputs with standard reference methods: gravimetric method for soil moisture, mercury thermometer for temperature, and laboratory chemical analysis for NPK levels. Mean absolute error (MAE) and standard deviation were calculated for each parameter to quantify performance. System testing was conducted to ensure the tool's reliability and functional accuracy:

1. Functional Testing: Analyzes whether each component, both sensors and actuators, operates according to specifications individually and as part of the integrated system.
2. Sensor Accuracy Testing: Accuracy validation is conducted by comparing sensor measurements with standard methods such as gravimetry for soil moisture.

The testing results show that the designed system operates effectively and efficiently and is capable of meeting farmers' needs. The error rate remains within an acceptable range for field applications, making the system feasible for wider-scale implementation.

RESULTS AND DISCUSSION

This study focuses on the utilization of the Simosachi application in the cultivation of *Sacha Inchi* plants, particularly in the aspects of fertigation monitoring and harvest data recording. The research results indicate that the Simosachi application offers several key features relevant to *Sacha Inchi* cultivation:

1. Fertigation Monitoring
   a. Real-time display of soil condition data, including moisture, temperature, and nutrient levels (N, P, K).
   b. Monitoring and control of the fertilizer pump, enabling farmers to regulate fertilization based on plant requirements.
   c. Similar solar-powered IoT-based fertigation control systems have been shown to improve nutrient delivery efficiency [13].
2. Harvest Recording
   a. The integrated weighing feature allows for precise recording of Sacha Inchi seed weights.
   b. Fertilization activities and harvest records are systematically stored and tracked.
   c. The system supports structured and efficient data management during the post-harvest phase.

Overall, the system promotes precision agriculture through improved monitoring, control, and recordkeeping. These capabilities enhance decision-making, resource optimization, and productivity.

A. Hardware Testing

Hardware testing is a critical phase in the development of the Simosachi application to ensure system performance and reliability. Several aspects of testing were conducted:

1. Sensor Testing

Soil Moisture Sensor Accuracy Sensor accuracy was evaluated through comparison with measurements obtained via the gravimetric method. Results are summarized in Table 1. The soil moisture content (%) was calculated using the gravimetric method with the formula: **Moisture (%) = (Wet Weight – Dry Weight) / Dry Weight × 100%**. The calculations were performed in Microsoft Excel to ensure accuracy and consistency.

Table 1. Soil Moisture Sensor Accuracy Test Using Gravimetric Method

No	Soil Sample	Wet Weight (g)	Dry Weight (g)	Moisture (%)	Description
1	A1	55.2	48.5	13.8	Moist
2	A2	62.3	54.1	15.1	Moist
3	B1	49.7	45.3	9.7	Slightly Dry
4	B2	58.8	51.2	14.8	Moist
5	C1	42.1	39.6	6.3	Dry
	Average			12.0	Moist

Source: (Research Results, 2025)

Note: Moisture values were calculated using the gravimetric method formula in Microsoft Excel.

Temperature Sensor Accuracy Sensor data were compared with standard thermometer readings. All differences were within acceptable margins (±0.2°C).

Table 2. Soil Temperature Sensor Test

No	Sensor Reading (°C)	Standard Thermometer (°C)	Difference (°C)	Notes
1	25.2	25.0	0.2	Clear
2	28.3	28.1	0.2	Clear
3	23.7	23.5	0.2	Cloudy
4	26.8	26.6	0.2	Afternoon
5	24.5	24.3	0.2	Morning
	Average	25.7	25.5	0.2

Source: (Research Results, 2025)

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NPK Sensor Accuracy Comparisons with laboratory test results demonstrated acceptable accuracy, with average deviation of ±2.5 mg/kg.

Table 3. NPK Sensor Accuracy Test

No	Nutrient	Sensor Reading (mg/kg)	Lab Result (mg/kg)	Difference (mg/kg)	Notes
1	N	120	118	2	Before fertilization
2	P	55	58	-3	Before fertilization
3	K	80	77	3	Before fertilization
4	N	155	152	3	Goat manure applied
5	P	88	91	-3	Goat manure applied
6	K	112	109	3	Goat manure applied
Average				2.5	

Source: (Research Results, 2025)

The minor deviations in sensor readings, such as ±2.5 mg/kg for NPK and ±0.2°C for temperature, can be attributed to factors including sensor calibration drift, soil heterogeneity, and micro-environmental variations around the probe location. Regular calibration before field deployment is therefore recommended to maintain accuracy.

2. Fertilizer Pump Testing

Functional Testing The system successfully responded to ON/OFF commands, verifying real-time control through the Simosachi app. Flow rate measurements complied with fertigation requirements.

Source: (Research Results, 2025)

Figure 8. Functional Test of Fertilizer Pump

Endurance Testing Continuous operation under various environmental conditions demonstrated robust performance and durability.

Source: (Research Results, 2025)

Figure 9. *Pump Endurance Test*

3. Weighing Device Testing

The load cell module was tested using reference weights to verify accuracy and consistency.

Table 4. Weight Sensor Accuracy Test

No	Reference Weight (g)	Measured Weight (g)	Difference (g)	Error (%)
1	56.7	56.8	0.1	0.18
2	145.6	147.0	1.4	0.96
3	37.3	37.3	0.0	0.00
4	868.7	879.9	11.2	1.29
5	8.9	8.2	0.7	7.87
		average		97.94%

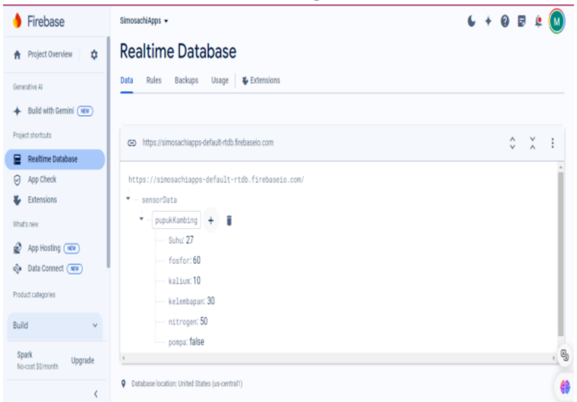
Source: (Research Results, 2025)

From table 4, Processed Data Meanwhile, the average accuracy of the sacha inch seed scale is 97.94%.

4. Software Testing

Software validation was conducted to assess the application's ability to correctly display sensor data and support weighing operations.

A. Sensor Data Monitoring Test



(a)

(b)

Source: (Research Results, 2025)

Figure 10. Sensor Data Monitoring Test

Sensor Data Display Test The application displayed real-time data indicating 30% soil moisture, NPK concentrations (N: 50 ppm, P: 60 ppm, K: 10 ppm), and a temperature of 27°C. The goat manure pump was reported inactive (OFF).

B. Weight Sensor Test (Weighing Device)

Source: (Research Results, 2025)

Figure 11. Weight Sensor Test Results

Weighing Module Functionality Testing confirmed successful operation of the weighing feature. On July 3, 2024, a total of 50 kg of Sacha Inchi seeds was recorded. The system successfully saved and exported the data in Excel format.

During field implementation, intermittent internet connectivity was observed in remote plantation areas, causing temporary delays in data synchronization. Variations in sensor readings were also noted during periods of high rainfall, possibly due to water accumulation on the soil surface affecting moisture measurements. These findings highlight the importance of incorporating offline data caching and rain-compensation algorithms in future system iterations.

Compared to the automated fertigation system developed by [14], which lacked integrated yield measurement, the proposed system combines fertigation control with post-harvest seed weight monitoring in a single platform. This integration reduces labor requirements and provides comprehensive datasets for decision-making. Furthermore, while previous studies such as [15] focused primarily on generic smart farming architectures, this research tailors IoT applications to the specific agronomic requirements of Sacha Inchi in Indonesia. This aligns with recent developments in IoT-enabled smart irrigation systems that emphasize sustainable water use and real-time monitoring [16]

CONCLUSION

Based on the testing results of the fertigation system (irrigation and fertilization) and the seed weight detection tool for Sacha Inchi that have been designed and developed, this study concludes that the integrated system provides an effective IoT-based solution to support modern agricultural practices. The system combines fertigation monitoring and control with post-harvest seed weighing in a single embedded system.

Through the Simosachi application, farmers are able to monitor soil conditions in real time—including moisture, temperature, pH, and nutrient levels—and remotely control irrigation and fertilization processes. The harvest recording feature also enables farmers to manage production data efficiently, which is beneficial for future yield evaluation and prediction. The seed weight detection tool demonstrated a high accuracy rate of 97.94%, significantly supporting post-harvest activities. The implementation of Internet of Things (IoT) technology in this study facilitates seamless real-time communication and control between hardware devices, mobile applications, and end users. This integrated approach is expected to enhance productivity, decision-making, and data-driven agricultural management, while offering potential for further development toward precision farming and scalable automation. However, this study has several limitations. The system's performance relies on stable internet connectivity, which may not always be available in remote agricultural areas. Additionally, field testing was conducted in a single geographic location and over a limited seasonal period, which may not fully represent diverse agro-climatic conditions in Indonesia.

Future research should focus on integrating offline data caching capabilities, expanding testing to multiple regions and crop cycles, and developing predictive analytics algorithms to optimize fertigation scheduling. Incorporating renewable energy sources such as

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solar power could also improve system sustainability in off-grid areas.

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