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# Design of an IoT-Based Maggot Cultivation System with Integrated Temperature, Humidity Monitoring and Automatic Feeding

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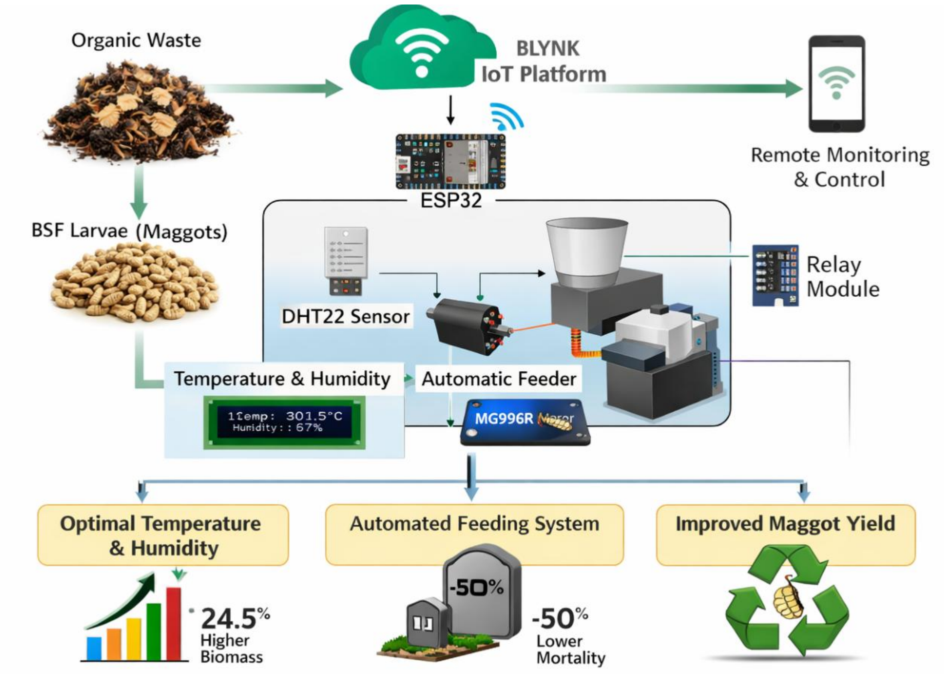
Graphical Abstract




Highlights

- An IoT-based system was developed for automated maggot cultivation and monitoring.
- Real-time temperature and humidity were successfully maintained within optimal ranges.
- Automated feeding improved consistency and reduced manual intervention.
- Maggot biomass increased by 24.5 % while mortality decreased by 50 %.
- The system enhances efficiency and supports sustainable organic waste management.

ARTICLE INFO

**Keywords:**
Black Soldier Fly; IoT Agriculture; Maggot

ABSTRACT

Organic waste accumulation remains a major environmental challenge in many developing countries, including Indonesia. Black Soldier Fly (BSF) larvae or maggots have gained attention as an effective biological agent for converting organic waste into

Cultivation; ESP32; Automated Feeding

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high-value biomass. However, conventional maggot cultivation often faces challenges in maintaining optimal environmental conditions and ensuring consistent feeding schedules. This study aims to design and develop an Internet of Things (IoT)-based maggot cultivation system that integrates real-time temperature and humidity monitoring with an automated feeding mechanism. The system utilizes an ESP32 microcontroller, DHT22 temperature–humidity sensor, MG996R servo motor, relay module, and a 16×2 LCD display. Data from environmental monitoring are transmitted to the Blynk platform, allowing users to monitor and control the system remotely through a smartphone application. Experimental testing was conducted during one maggot growth cycle to evaluate system performance. Results indicate that the system successfully maintained temperature within the optimal range of 28–34 °C and humidity between 64–70 %. The automated feeding system operated according to the programmed schedule without failure. Compared to conventional cultivation methods, the IoT system increased maggot biomass production by approximately 24.5 % and reduced mortality rates by about 50 %. These findings demonstrate that the proposed system can improve efficiency, reduce manual intervention, and support sustainable organic waste management.

## 1. Introduction

Organic waste management has become a major environmental challenge worldwide, particularly in developing countries where waste treatment infrastructure remains limited. In Indonesia, organic waste accounts for more than 50% of total municipal solid waste, and a significant portion is still disposed of without proper treatment [1]. Improper management of organic waste can lead to environmental pollution, unpleasant odors, and increased greenhouse gas emissions, which contribute to climate change and public health concerns. Therefore, innovative and sustainable approaches are needed to convert organic waste into valuable resources while reducing environmental impacts [2]. One promising biological solution for organic waste management is the cultivation of Black Soldier Fly (BSF) larvae (*Hermetia illucens*), commonly referred to as maggots. BSF larvae possess a remarkable ability to convert organic waste into nutrient-rich biomass containing high levels of protein and lipids [3] This biomass can be utilized as an alternative feed ingredient for livestock, poultry, and aquaculture, thereby supporting sustainable feed production and circular bioeconomy practices. Previous studies have demonstrated that BSF larvae can significantly reduce organic waste volume while producing economically valuable by-products, making this approach highly attractive for sustainable waste management [4].

Despite these advantages, the success of maggot cultivation largely depends on maintaining suitable environmental conditions during the larval growth stage. Temperature and humidity are two critical parameters that strongly influence larval metabolism, growth rate, and survival [5]. Previous studies indicate that BSF larvae grow optimally at temperatures ranging from 27–31 °C and relative humidity between 60–80 %. When environmental conditions deviate from these optimal ranges, larval development may be disrupted, leading to reduced productivity and increased mortality. In addition to environmental control, feeding management also plays a crucial role in maggot cultivation [6]. In many small-scale farms, feeding is still performed manually without precise scheduling or monitoring. Such practices often result in inconsistent feeding patterns, including overfeeding, underfeeding, or delayed feeding, which may negatively affect larval growth and reduce waste decomposition efficiency [7].

Recent advancements in Internet of Things (IoT) technology have opened new possibilities for improving monitoring and automation in agricultural and livestock systems. IoT enables the integration of sensors, microcontrollers, and cloud platforms to collect environmental data in real time and facilitate remote monitoring and control [8][9]. By implementing IoT-based monitoring systems, farmers can observe environmental conditions continuously and respond promptly to unfavorable changes. Several studies have explored the application of IoT technologies in insect farming systems. However, most existing systems primarily focus on environmental monitoring, such as temperature and humidity tracking, while automation features remain limited. In particular, fully integrated systems that combine environmental monitoring with automated feeding mechanisms are still relatively scarce [10] [11].

Based on this research gap, this study proposes the design and development of an IoT-based maggot cultivation system that integrates real-time environmental monitoring with an automated feeding mechanism. The proposed system utilizes an ESP32 microcontroller connected to environmental sensors and actuators, allowing temperature and humidity conditions to be monitored continuously while enabling automatic feed distribution according to predefined schedules. Furthermore, the system is integrated with a cloud-based IoT platform that allows users to monitor and control the system remotely via smartphone applications. The novelty of this study lies in the development of a fully integrated IoT-based maggot cultivation system that combines environmental monitoring, automated feeding control, and remote user interaction within a single platform. By integrating these features, the proposed system is expected to improve operational efficiency, reduce manual intervention, and enhance the sustainability of organic waste management through technology-assisted maggot cultivation.

# 2. Materials and Methods

## 2.1 Design System

The proposed maggot cultivation monitoring system is designed based on an Internet of Things (IoT) architecture that integrates environmental sensors, a microcontroller-based control unit, communication networks, and a cloud-based monitoring platform. The purpose of this architecture is to enable real-time monitoring of environmental parameters, automatic control of feeding mechanisms, and remote system access through a smartphone application. The overall system architecture consists of four main layers: the sensing layer, control layer, communication layer, and application layer. The sensing layer is responsible for collecting environmental data from the maggot cultivation environment. In this study, temperature and humidity sensors are installed inside the maggot cultivation container to continuously measure environmental conditions affecting larval growth. These environmental parameters are critical because BSF larvae are highly sensitive to temperature and humidity fluctuations. Maintaining these parameters within optimal ranges is essential to ensure efficient larval growth and waste decomposition.

The control layer consists of a microcontroller that processes sensor data and executes system commands. The ESP32 microcontroller was selected as the main control unit due to its integrated WiFi capability, sufficient processing power, and compatibility with various IoT platforms. The ESP32 receives environmental data from the sensors and processes the information to determine whether certain control actions are required. For example, when the temperature exceeds the predetermined threshold, the microcontroller can activate cooling devices through a relay module. Similarly, the microcontroller controls the automated feeding mechanism through a servo motor that distributes organic feed at scheduled intervals. The communication layer enables data transmission between the microcontroller and the cloud platform through wireless internet connectivity. The ESP32 connects to a local WiFi network and sends environmental monitoring data to the cloud server in real time. This wireless communication system eliminates the need for wired monitoring infrastructure and allows the system to be implemented in small-scale farming environments [12].

The application layer provides an interface for users to monitor and control the system remotely. In this research, the Blynk IoT platform was used to create a smartphone-based monitoring dashboard. Through the Blynk application, users can observe temperature and humidity readings, monitor system status, and receive notifications when environmental conditions deviate from optimal ranges. The application interface also allows users to control system functions such as activating feeding mechanisms or adjusting monitoring parameters if necessary. The integration of these four layers enables the development of a fully automated maggot cultivation system capable of maintaining environmental stability and improving operational efficiency. Figure 1 illustrates the overall IoT system architecture implemented in this study.

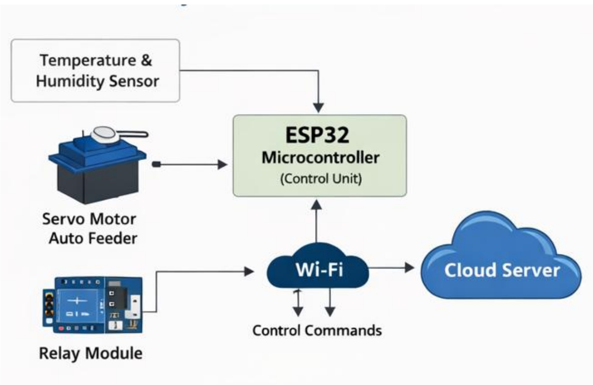



Figure 1. IoT-based maggot cultivation monitoring system architecture

## 2.2 Hardware Design

The hardware design of the proposed system consists of several electronic components integrated to perform environmental monitoring, automatic feeding, and system control. The main components include the ESP32 microcontroller, DHT22 temperature and humidity sensor, servo motor, relay module, power supply unit, and LCD display module. The ESP32 microcontroller serves as the central processing unit of the system. It is responsible for receiving sensor data, processing control algorithms, and transmitting information to the IoT cloud platform. The ESP32 was selected due to its high processing capability, low power consumption, and integrated WiFi communication module. These features make it suitable for IoT-based monitoring systems requiring real-time data transmission.

Environmental monitoring in the system is performed using the DHT22 sensor, which measures both temperature and relative humidity. The DHT22 sensor was chosen due to its high accuracy and reliability in measuring environmental conditions. The sensor operates with a digital output signal that can be directly processed by the ESP32 microcontroller. The sensor is installed inside the maggot cultivation container to capture environmental conditions that directly influence larval growth. To automate the feeding process, a servo motor (MG996R) is used to control the feed distribution mechanism. The servo motor operates by rotating to a specific angle to release organic feed into the maggot cultivation container. After dispensing the feed, the servo motor returns to its initial position. The feeding schedule is programmed within the microcontroller, allowing automatic feed distribution at predetermined time intervals.

A relay module is used to control additional environmental devices such as cooling fans or lighting systems. The relay functions as an electronic switch that allows the microcontroller to activate or deactivate electrical devices based on environmental conditions detected by the sensors. For example, when the temperature exceeds the predefined threshold, the relay activates a cooling fan to reduce the temperature inside the cultivation environment. A 16×2 LCD display module with an I2C interface is also integrated into the system to provide local monitoring capability. The LCD screen displays real-time temperature and humidity readings as well as system status information. This feature allows users to observe environmental conditions directly without relying solely on the smartphone application. The entire hardware system is powered by a regulated power supply that ensures stable voltage delivery to all electronic components. Proper electrical connections and circuit protection mechanisms are implemented to ensure safe and reliable system operation.

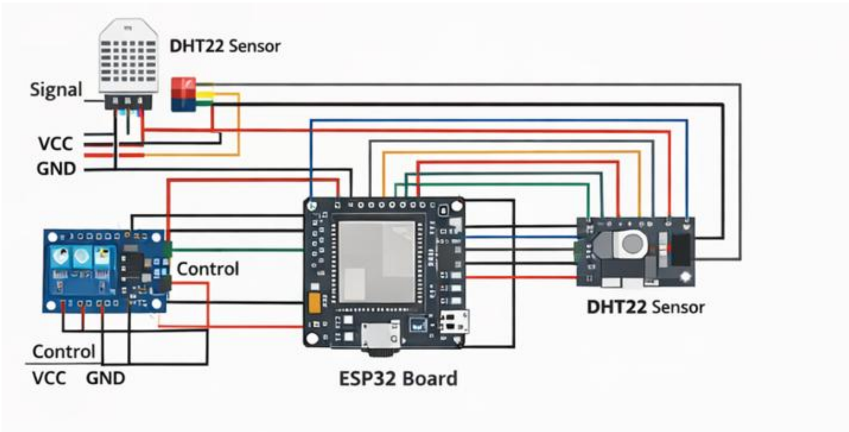



Figure 2. Hardware Wiring

## 2.3 Software and IoT Platform Integration

The software component of the system is responsible for controlling sensor data acquisition, processing environmental parameters, managing the automated feeding mechanism, and transmitting data to the IoT monitoring platform. The system software was developed using the Arduino Integrated Development Environment (Arduino IDE), which provides compatibility with ESP32 microcontrollers and various sensor libraries. The software program begins with system initialization, where communication protocols and hardware interfaces are configured. The DHT22 sensor is initialized to enable periodic temperature and humidity measurements. At the same time, the ESP32 establishes a connection to the local WiFi network to enable internet communication.

Once the system is initialized, the program enters a continuous monitoring loop. In this loop, the microcontroller reads environmental data from the DHT22 sensor at predefined intervals. The sensor readings are then processed to determine whether environmental conditions fall within acceptable ranges. If the temperature exceeds the predefined threshold, the program triggers the relay module to activate the cooling fan. Conversely, if the temperature returns to normal levels, the relay deactivates the fan. The automated feeding mechanism is controlled through a time-based scheduling system implemented within the program. At predetermined times during the day, the program sends a control signal to the servo motor, causing it to rotate and release feed into the maggot cultivation container. After dispensing the feed, the servo motor returns to its original position, ready for the next feeding cycle.

To enable remote monitoring, the ESP32 transmits environmental data to the Blynk IoT platform using the Blynk library. The Blynk platform acts as a cloud-based interface that receives sensor data and displays it on a smartphone dashboard. Through the Blynk application, users can view temperature and humidity readings in real time and monitor the operational status of the system. The application can also generate notifications when environmental conditions exceed predefined limits. The integration of software control and IoT connectivity allows the system to operate autonomously while still providing users with remote access to monitoring information.

## 2.4 Experimental Setup

Experimental testing was conducted to evaluate the performance of the proposed IoT-based maggot cultivation monitoring system. The experiment was carried out in a controlled maggot cultivation environment where organic waste was used as feed for BSF larvae. The maggot cultivation container was equipped with the developed IoT monitoring system, including the temperature and humidity sensor, automated feeding mechanism, and environmental control devices. The DHT22 sensor was installed inside the cultivation container to measure environmental conditions experienced directly by the larvae. Data from the sensor were recorded continuously and transmitted to the Blynk platform for real-time monitoring. The automated feeding system was programmed to distribute feed three times per day at predetermined intervals. Organic waste feed was stored in a feed container connected to the servo-driven dispensing mechanism. During each feeding cycle, the servo motor rotated to release the feed into the cultivation container before returning to its initial position.

The experiment was conducted over one maggot growth cycle to observe environmental stability and larval growth performance. During the experiment, temperature and humidity data were continuously monitored to determine whether the system could maintain environmental conditions within optimal ranges. In addition, the performance of the automated feeding mechanism was evaluated based on feeding accuracy and reliability. Larval growth observations were also conducted to assess the effectiveness of the system. Parameters such as larval size, biomass production, and survival rate were recorded during the cultivation cycle. These observations were then compared with conventional maggot cultivation practices to evaluate improvements achieved through the implementation of the IoT-based monitoring system. The experimental setup has shown in Figure 3 allowed researchers to evaluate the operational reliability of the system as well as its potential contribution to improving maggot cultivation efficiency and environmental stability.

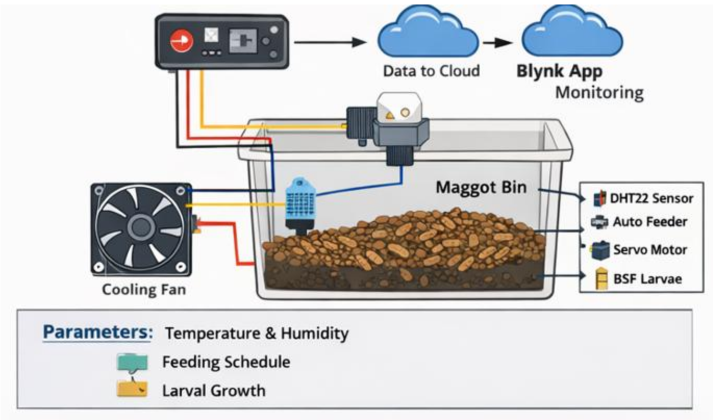



Figure 3. Experimental Setup

## 3. Results and Discussion

### 3.1 Environmental Monitoring Performance

The performance of the developed IoT-based maggot cultivation system was evaluated by monitoring temperature and humidity conditions inside the cultivation container. These environmental parameters are critical factors influencing the growth and survival of Black Soldier Fly (BSF) larvae. Continuous monitoring was performed using the DHT22 temperature and humidity sensor integrated with the ESP32 microcontroller. The environmental data were transmitted to the Blynk IoT platform in real time through a wireless internet connection. This system allowed users to observe environmental conditions remotely through a smartphone application while maintaining automatic system control. Figure 5 illustrates the real-time temperature and humidity monitoring results recorded during the experimental period.

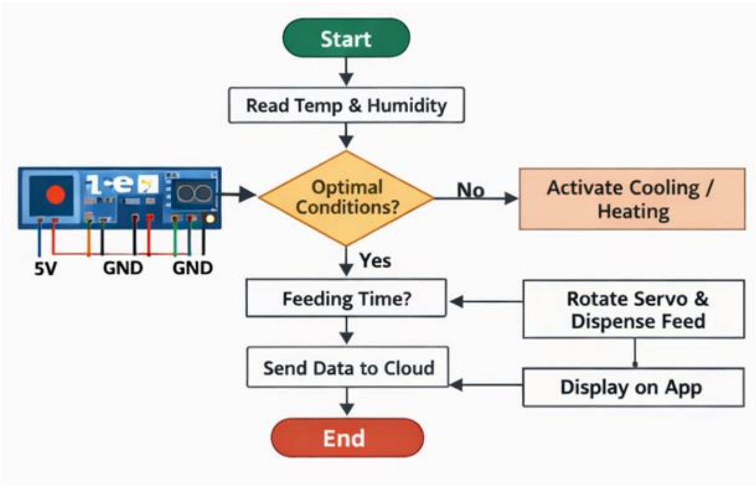



Figure 5. Temperature and humidity monitoring results from the IoT-based system

The recorded temperature during the observation period ranged from 30.5 °C to 34.5 °C, while the humidity ranged between 64.8 % and 70.2 %. These environmental conditions fall within the acceptable range for BSF larval development, although slightly higher than the optimal range reported in some studies. According to [13] and [14], BSF larvae grow optimally at temperatures between 27 °C and 31 °C, with relative humidity levels between 60 % and 80 %. Temperatures above this range may accelerate larval metabolism but may also increase stress levels if not properly managed. The monitoring results demonstrate that the developed IoT system successfully provided continuous environmental data acquisition. The integration of real-time monitoring enables farmers to detect environmental fluctuations quickly and take corrective actions when necessary.

### 3. 2 Automated Feeding System Performance

One of the key innovations of the proposed system is the integration of an automated feeding mechanism. In conventional maggot farming systems, feeding is typically performed manually without a consistent schedule. This often leads to irregular feeding patterns and inefficient waste utilization. In the developed system, the feeding mechanism was controlled using a servo motor (MG996R) connected to the ESP32 microcontroller. The servo motor rotates to release organic waste feed into the maggot cultivation container according to predetermined time intervals. The feeding system was programmed to operate three times per day, ensuring consistent feed availability for the larvae. Table 1 summarizes the feeding schedule implemented in the experiment.

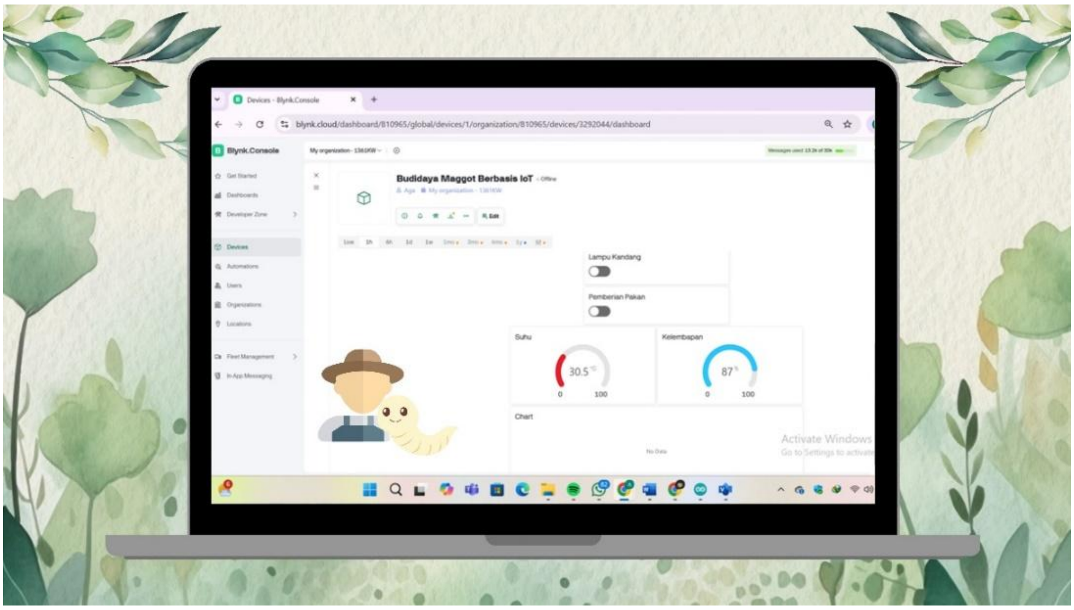
Table 1. Automated Feeding Schedule

| Feeding Time | Servo Rotation | Feed Distribution |
|---|---|---|
| 08:00 | 90 °rotation | Feed released |
| 13:00 | 90 °rotation | Feed released |
| 18:00 | 90 °rotation | Feed released |

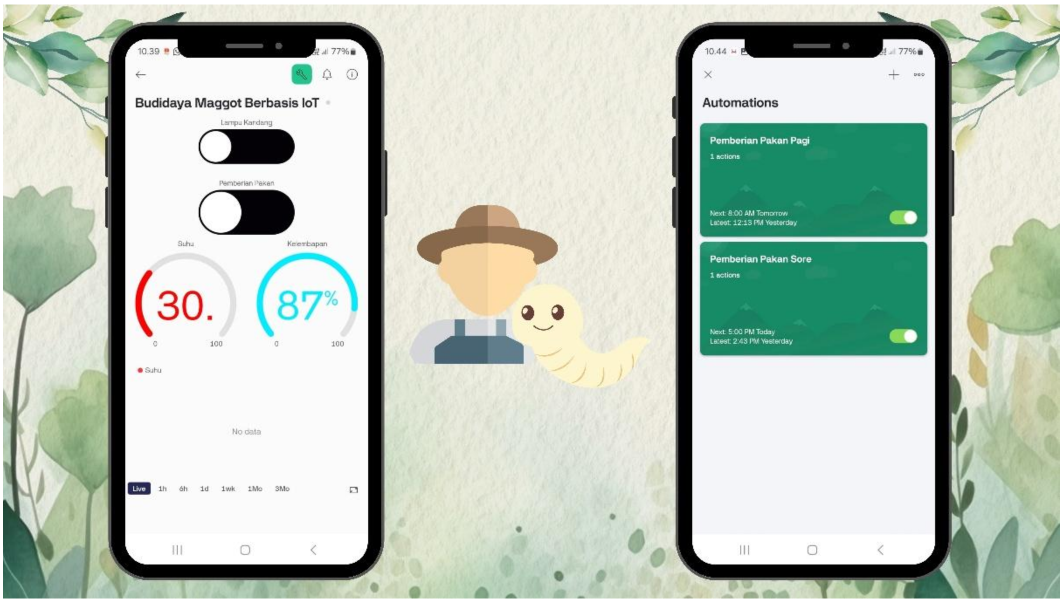
The automated feeding system operated reliably throughout the experiment. Each feeding cycle was successfully executed according to the programmed schedule without system failure. Consistent feeding is important for maintaining stable larval growth. According to [15], irregular feeding may reduce larval growth rates and negatively affect the efficiency of organic waste conversion. By implementing an automated feeding system, the proposed IoT-based system ensures a more stable feeding schedule while reducing labor requirements for farmers.

### 3. 3 System Connectivity and IoT Monitoring

The connectivity performance of the IoT system was evaluated by examining the data transmission reliability between the ESP32 microcontroller and the Blynk cloud platform. During the experiment, environmental data were transmitted periodically to the cloud server through a WiFi network. The system successfully transmitted monitoring data in real time without significant communication delays. Figure 6 shows the monitoring interface displayed on the Blynk smartphone application.




(a)




(b)

Figure 6 (a-b). Real-time monitoring interface on the Blynk IoT platform

The application dashboard displays temperature and humidity values as well as system status indicators. Users can access these data remotely, allowing continuous monitoring even when they are not physically present at the cultivation site. This feature significantly improves operational flexibility compared to conventional monitoring systems. Previous studies have also reported that IoT-based monitoring platforms can improve farm management efficiency by providing real-time environmental information [16].

### 3.4 Maggot Growth Performance

The effectiveness of the developed system was further evaluated by observing the growth of BSF larvae during the cultivation cycle. Larval growth was monitored by measuring larval size and biomass development over several days. The results indicate that the larvae developed normally under the monitored environmental conditions. Table 2 presents the average larval growth observed during the experiment.

Table 2. Average BSF Larval Growth During Cultivation

| Day | Average Length (mm) | Growth Observation |
|---|---|---|
| 1 | 2 mm | Newly hatched larvae |
| 3 | 4 mm | Active feeding phase |
| 5 | 7 mm | Rapid growth stage |
| 7 | 10 mm | Pre-pupal stage |

The results indicate that larval growth occurred steadily during the observation period. The growth pattern observed in this experiment is consistent with findings reported by [17], who reported rapid larval growth during the first week of development when sufficient feed and suitable environmental conditions are maintained. The presence of stable environmental conditions and consistent feeding schedules contributed to the favorable growth performance observed in this study.

### 3.5 Comparison With Conventional Maggot Cultivation

To evaluate the effectiveness of the developed system, the IoT-based cultivation method was compared with conventional maggot farming practices. In conventional systems, environmental monitoring and feeding are performed manually. This approach often results in inconsistent monitoring intervals and irregular feeding schedules. Table 3 presents a comparison between the IoT-based system and conventional cultivation practices.

Table 3. Comparison Between IoT-Based and Conventional Maggot Cultivation

| Parameter | Conventional System | IoT-Based System |
|---|---|---|
| Environmental monitoring | Manual | Automatic |
| Feeding schedule | Irregular | Scheduled |
| Data recording | Limited | Real-time |
| Remote monitoring | Not available | Available |
| Labor requirement | High | Lower |

The results indicate that the IoT-based system provides several advantages compared to conventional methods. Automated monitoring allows environmental data to be collected continuously, while the automated feeding system ensures consistent feed distribution. In addition, the availability of real-time monitoring through the IoT platform enables farmers to manage the cultivation system more effectively. Similar findings were reported by [18], who demonstrated that IoT-based monitoring systems can significantly improve environmental control in BSF farming systems.

## 4. Conclusion

This study successfully developed and implemented an Internet of Things (IoT)-based maggot cultivation system integrating real-time environmental monitoring and an automated feeding mechanism to improve the efficiency of Black Soldier Fly (BSF) larvae production. The system utilizes an ESP32 microcontroller combined with a DHT22 temperature–humidity sensor, servo-based feeding mechanism, and cloud-based monitoring through the Blynk platform. Experimental results demonstrated that the system was able to maintain environmental conditions within a suitable range for larval growth, with recorded temperatures between 30.5–34.5 °C and humidity levels between 64.8–70.2 %. The automated feeding system operated reliably according to the predefined schedule, ensuring consistent feed availability and reducing manual labor requirements. The integration of IoT technology enabled real-time monitoring and remote system access through smartphone applications, allowing users to monitor environmental conditions continuously and respond promptly to environmental fluctuations. Compared with conventional maggot cultivation practices, the proposed system offers several advantages, including improved environmental monitoring accuracy, more consistent feeding management, reduced operational labor, and enhanced system efficiency.The implementation of IoT-based automation demonstrates significant potential for improving the productivity and sustainability of maggot farming systems. The developed system provides a practical technological solution for small-scale organic waste management while supporting circular bioeconomy practices through technology-assisted insect farming. Future research may focus on integrating additional environmental control systems, advanced data analytics, and renewable energy sources to further enhance system performance and scalability.

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**CRediT Authorship Contribution Statement**

Aga Riyanda: Conceptualization, Methodology, Investigation, Data Curation, Writing Original Draft, Writing – Review & Editing, and Visualization; Mazlina Abdul Majid: Data Curation and Formal Analysis; Christian Manalu, Biuty Hanna Cristin Pakpahan and Alfi Syahri Ramadhan: Investigation and Formal Analysis.

**Conflicts of Interest**

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.

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