

Empowering Oyster Mushroom Farmers through IoT-Based Smart Mushroom House for Climate Adaptation

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Abstract: *Climate variability challenges oyster mushroom cultivation by disrupting optimal temperature and humidity conditions, particularly during the dry season. This community engagement program aimed to implement an Internet of Things (IoT)-based Smart Mushroom House system to support adaptive and sustainable mushroom cultivation. The program was conducted with the Alugoro Youth Farmer Group in Sragen Regency, Indonesia, using a Participatory Rural Appraisal (PRA) approach involving socialization, training, IoT installation, assistance, and evaluation. The GrowMatic system integrated temperature and humidity sensors with automated irrigation control for real-time environmental management. Results showed improved farmer knowledge, with average scores increasing from 5.3 to 10.4 out of 11 questions (96.2% improvement). The system maintained cultivation conditions at 25–26°C temperature and 82–90% humidity while enabling farmers to operate the technology independently. This program demonstrates the potential of IoT-based solutions combined with participatory capacity building to strengthen climate-resilient oyster mushroom agribusiness.*

Keywords:

Climate Adaptation, Internet of Things, Oyster Mushroom Cultivation, Smart Farming, Farmer Empowerment

Introduction

Climate variability and increasing environmental uncertainty have become major challenges affecting agricultural production systems, particularly for commodities that require specific environmental conditions. Agricultural enterprises that depend on controlled microclimates are highly vulnerable to fluctuations in temperature, humidity, and seasonal changes. Oyster mushroom (*Pleurotus ostreatus*) cultivation is one of the agricultural activities that requires precise

environmental management because its growth and productivity are strongly influenced by temperature and relative humidity conditions. Therefore, developing adaptive technologies that enable efficient monitoring and regulation of cultivation environments has become increasingly important to improve the resilience of small-scale agricultural enterprises.

Oyster mushroom cultivation requires a relatively stable microclimate, with an optimal temperature range of approximately 24–27°C and relative humidity of 80–90% to support mycelial growth and fruiting body formation (Kristiyanti et al., 2022; Ntihung et al., 2024). However, maintaining these conditions remains challenging, particularly during prolonged dry seasons when high temperatures and low humidity can disrupt cultivation performance. Previous studies have demonstrated that inappropriate environmental conditions may reduce mushroom growth and productivity due to physiological stress and suboptimal fruiting processes (Sofwan et al., 2020; Hidayat et al., 2023).

This challenge is particularly evident among small-scale oyster mushroom farmers in Sragen Regency, Indonesia. Based on field observations, oyster mushroom production may reach approximately 65–80 kg per day during the rainy season but decreases substantially to only 4–10 kg per day during the dry season. The decline is associated with increased temperatures ranging from 31–34°C, humidity levels below 80%, and strong wind conditions with average speeds exceeding 8.7 km h⁻¹, which contribute to hotter and drier conditions inside mushroom cultivation houses. These environmental fluctuations create difficulties for farmers in maintaining optimal growing conditions and ensuring consistent production throughout the year.

The Alugoro Youth Farmer Group (Kelompok Tani Pemuda/KTP Alugoro) in Karangmalang Village, Masaran District, Sragen Regency, represents one of the community-based agricultural groups experiencing these challenges. The group has developed oyster mushroom cultivation activities supported through a partnership program involving Perum BULOG's Social and Environmental Responsibility (TJSL) initiative and the Agribusiness Study Program, Vocational School, Universitas Sebelas Maret. Through this initiative, the group received support in establishing an oyster mushroom cultivation house with an area of 84 m² and a production capacity of 6,000 mushroom bags, accompanied by technical cultivation training. Although the production facility has provided a foundation for agribusiness development, maintaining suitable environmental conditions remains a critical constraint, particularly during dry periods.

Prior to technological intervention, mushroom house management relied on conventional practices, including manual watering twice daily and the use of mulch around the cultivation house to maintain humidity. However, these approaches were insufficient to maintain stable environmental conditions because water rapidly evaporated under high-temperature conditions. The limitation of conventional management highlights the need for an adaptive and efficient approach capable of providing continuous environmental monitoring and automatic control to support sustainable mushroom cultivation.



Figure 1. (a) and (b) Mushroom condition during the dry season; (c) Mulch as a covering material for the mushroom cultivation house

The development of Internet of Things (IoT)-based smart farming technologies provides an opportunity to address these challenges. IoT systems enable real-time monitoring of environmental parameters, including temperature and humidity, while allowing automated responses based on predefined cultivation requirements. Previous studies have shown that IoT applications in mushroom cultivation can improve environmental control accuracy, reduce dependence on manual labour, and support more efficient resource management (Shakir et al., 2019; Subedi et al., 2019; Widyasmoro et al., 2023). Through the integration of sensors, control units, and automated irrigation systems, IoT technology can support the transformation of conventional cultivation systems into more adaptive and resilient agricultural practices.

Based on these considerations, this community engagement program aimed to implement an IoT-based Smart Mushroom House system as an adaptive solution for improving environmental management in oyster mushroom cultivation. The program focused not only on technology installation but also on strengthening farmers' capacity to operate and manage digital agricultural systems independently. Through participatory technology transfer involving farmer groups, academic institutions, and supporting stakeholders, this initiative is expected to contribute to the development of climate-resilient, sustainable, and technology-driven local agribusiness systems.

Methods

This community engagement program was conducted using the Participatory Rural Appraisal (PRA) approach, which is a participatory empowerment method that emphasizes active community involvement throughout the development process (Sidiq & Resnawaty, 2017; Munawar, 2019). Through the PRA approach, community members are not positioned merely as recipients of externally designed interventions (top-down approach), but rather as active actors who participate in designing and implementing development initiatives through a bottom-up process. This approach encourages community participation in program planning, priority identification, resource allocation, implementation, and utilization of outcomes at the local level (Syaputri, 2022).

The community engagement activities were conducted from May to August 2025 in Sragen Regency. The program began with an initial field survey and problem identification process to assess the conditions, challenges, and specific needs of the partner group. The preliminary survey was conducted through direct visits and discussions with KTP Alugoro members to introduce the objectives of the program, establish a shared understanding, and identify priority issues related to oyster mushroom cultivation that could be addressed through technological intervention.

Based on the results of the initial assessment and discussions with the partner group, the implementation of the program was divided into five main stages: (1) program socialization; (2) training and technology transfer of IoT technology in the mushroom cultivation house; (3) installation and implementation of IoT technology in the mushroom cultivation house.

Result

A. Implementation of IoT-Based Smart Mushroom House Technology

The community engagement program conducted with the Alugoro Youth Farmer Group (KTP Alugoro), Sragen Regency, resulted in the successful implementation of an Internet of Things (IoT)-based monitoring and control system in the oyster mushroom cultivation house. The program consisted of five sequential activities, including program socialization, technology training and transfer, IoT system installation, technical assistance, and program evaluation.

1. Program Socialization

The initial stage of the program was conducted through direct coordination and socialization with representatives of KTP Alugoro management. The activity involved the group leader, treasurer, and agricultural input division representatives. The socialization activity focused on introducing the objectives of the program, identifying cultivation problems experienced by the partner group, and determining the technical implementation plan.



Figure 2. Initial coordination and socialization activities conducted with the farmer group management

The results of the discussion showed that maintaining stable temperature and humidity conditions during the dry season was identified as the main challenge in oyster mushroom cultivation. Based on the agreement between the community engagement team and the partner group, the technical training activity was scheduled for 14 July 2025 and involved 10 participants consisting of farmer group administrators and mushroom cultivation house managers.

2. Training and Technology Transfer of IoT-Based Smart Mushroom House System

The training activity introduced the GrowMatic system, an IoT-based technology designed for monitoring temperature and humidity conditions and controlling automatic watering systems in oyster mushroom cultivation houses. The training participants received practical instruction regarding the components and operation of the IoT system, including:

- a. DHT22 temperature and humidity sensors;
- b. ESP32 microcontroller;
- c. relay modules;
- d. automatic water pump systems;
- e. web-based monitoring dashboards.



Figure 3. (a) Demonstration of IoT device operation by the trainer; (b) Participants involved in IoT-based Smart Mushroom House training and technology transfer activities

The training was conducted using a combination of theoretical explanation and hands-on practice. Participants practiced operating the GrowMatic system, reading real-time temperature and humidity data, and understanding the automatic irrigation control mechanism.

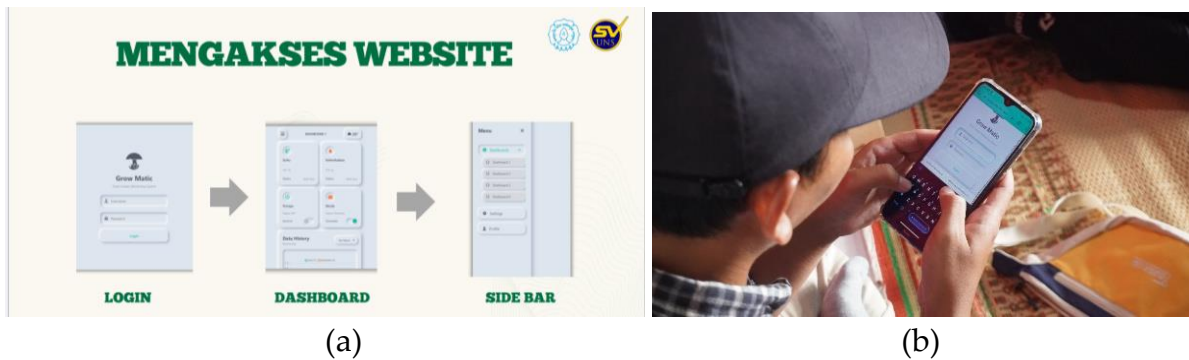


Figure 4. (a) Mushroom cultivation house manager accessing the GrowMatic application via smartphone; (b) User interface of the GrowMatic monitoring system

The effectiveness of the training was evaluated using pre-test and post-test assessments. The average pre-test score obtained by participants was 5.3 out of 11 questions, while the average post-test score increased to 10.4 out of 11 questions. The results showed an increase in participants' knowledge regarding IoT-based oyster mushroom cultivation management by 96.2%.



Figure 5. Participants undertaking the post-training evaluation through a post-test assessment

Following the training, participants were able to access the monitoring dashboard, interpret sensor data, and understand the operation of automatic watering control based on environmental conditions.

3. Installation and Implementation of IoT System in Oyster Mushroom Cultivation House

The IoT system was subsequently installed in the oyster mushroom cultivation house owned by KTP Alugoro. The installed system consisted of temperature and humidity sensors (DHT22), NodeMCU ESP32 as the main control unit, a 12VDC water pump, and an automatic sprinkler system. The system was integrated with the monitoring application, allowing users to observe environmental conditions and perform manual control through smartphone devices.



Figure 6. Installation of the IoT-based system in the Smart Mushroom House

The installation process was completed within two days, followed by system testing. The sensor system successfully transmitted temperature and humidity data in real-time, while the automatic sprinkler system operated based on predetermined

environmental thresholds. The sprinkler was activated when the temperature exceeded 27°C or when humidity decreased below 80%.

After system implementation, the environmental conditions inside the mushroom cultivation house were maintained within the target range, with temperature values ranging from 25–26°C and humidity levels ranging from 82–90%.

4. Assistance and Optimization of IoT System Operation

Following the installation process, technical assistance was conducted for one month to support system operation and adaptation by the partner group. The assistance activities included system maintenance, basic troubleshooting, adjustment of temperature and humidity settings, and management of monitoring data.

During the assistance period, observations showed that partner members were able to operate the IoT system independently. The mushroom house managers were able to access the monitoring dashboard, monitor temperature and humidity conditions, and perform routine system maintenance.

Participants also gained practical skills in adjusting watering schedules and monitoring environmental conditions based on sensor information.

5. Program Monitoring and Evaluation

Program evaluation was conducted through direct observation, interviews with participants, and comparison of mushroom house conditions before and after IoT system implementation. Several outcomes were recorded after the implementation of the IoT-based Smart Mushroom House system:

- a. The system successfully maintained temperature and humidity conditions within the recommended range throughout the cultivation period.
- b. Partner members were able to independently operate the *GrowMatic* system, including accessing the dashboard, reading temperature and humidity indicators, and activating manual or automatic watering modes.
- c. The implementation of automatic watering reduced the need for manual watering activities that previously had to be conducted twice daily.
- d. More than 80% of participants were able to operate the *GrowMatic* system independently after the training and assistance period.

Based on participant feedback, the system was considered easy to operate and useful for supporting oyster mushroom cultivation management, particularly during the dry season. The implementation of IoT technology enabled automatic watering

based on sensor readings, allowing humidity levels to be maintained within the range of 80–90%.

Discussion

A. IoT-Based Smart Mushroom House as a Climate Adaptation Strategy for Oyster Mushroom Cultivation

The implementation of an IoT-based Smart Mushroom House at KTP Alugoro demonstrates the potential of digital technology as an adaptive strategy to address environmental challenges in oyster mushroom cultivation. Oyster mushrooms require relatively stable microclimatic conditions, particularly temperature and humidity, to support optimal mycelial growth and fruiting body development. However, maintaining these conditions through conventional management practices remains challenging, especially during the dry season when high temperatures and low humidity can negatively affect production performance.

Prior to the intervention, mushroom house management relied mainly on manual watering practices to maintain humidity levels. However, this approach was unable to provide consistent environmental control due to rapid water evaporation under high-temperature conditions. The integration of IoT technology through the GrowMatic system enabled continuous monitoring and automatic regulation of cultivation conditions based on real-time sensor data. This capability allowed environmental parameters inside the mushroom house to be maintained within the required range, with temperatures of 25–26°C and humidity levels of 82–90%.

These findings support previous studies indicating that IoT-based environmental monitoring systems can improve the precision and efficiency of mushroom cultivation management by providing real-time information and automated control mechanisms (Sofwan et al., 2020; Hidayat et al., 2023). The ability to respond quickly to environmental fluctuations is particularly important in tropical production systems, where climate variability may increase production risks. Therefore, the application of IoT technology represents not only a technological improvement but also an adaptation mechanism to enhance the resilience of small-scale agricultural enterprises under changing climatic conditions.

B. Strengthening Farmer Capacity through Digital Technology Transfer

Beyond technological installation, the success of IoT adoption is strongly influenced by users' capacity to understand and operate the system. The significant improvement in participant knowledge after training, reflected by the increase in

average scores from 5.3 to 10.4, indicates that technology transfer activities effectively improved farmers' understanding of digital-based cultivation management.

This result highlights the importance of combining technological innovation with human capacity development in community-based agricultural interventions. Previous studies have emphasized that technology adoption among farmers is not solely determined by the availability of devices but also by farmers' technological literacy, perceived usefulness, and confidence in operating new systems (Mauladi & Yusuf, 2023).

The hands-on training approach applied in this program enabled participants to directly interact with IoT components, interpret sensor readings, and understand the relationship between environmental conditions and cultivation management decisions. Such participatory learning processes are consistent with the principles of Participatory Rural Appraisal (PRA), where communities are actively involved as technology users and decision-makers rather than passive recipients of innovation.

C. Improving Operational Efficiency and Supporting Sustainable Agribusiness Practices

The adoption of the GrowMatic system also contributed to improvements in operational efficiency by reducing dependence on manual watering activities. Before implementation, farmers were required to manually water the cultivation house twice daily to maintain humidity. Following IoT implementation, watering could be automatically controlled based on sensor measurements, reducing the workload associated with routine environmental management.

The integration of automated monitoring and irrigation systems provides opportunities for small-scale mushroom enterprises to improve resource efficiency, particularly in terms of labour and water management. Similar findings have been reported in previous IoT-based agricultural studies, where automation systems reduced manual intervention while improving environmental monitoring accuracy (Shakir et al., 2019; Subedi et al., 2019).

From an agribusiness perspective, reducing operational constraints is essential for improving production consistency and strengthening the competitiveness of small-scale producers. In the case of KTP Alugoro, IoT implementation supports the transition from conventional cultivation practices toward a technology-enabled agribusiness system that is more responsive to environmental changes and market demands.

D. Implications for Sustainable Agricultural Development and SDG Achievement

The implementation of IoT technology in oyster mushroom cultivation contributes to several Sustainable Development Goals (SDGs), particularly SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals).

The contribution to SDG 8 is reflected through the strengthening of local agribusiness capacity and improvement of production management efficiency. Meanwhile, the application of IoT technology represents an innovation-based agricultural approach aligned with SDG 9 by promoting digital transformation in rural production systems.

Furthermore, improved control of environmental conditions and more efficient resource utilization support the principles of responsible production under SDG 12. The role of IoT as an adaptation tool against climate-related production challenges also aligns with SDG 13, particularly in enhancing the resilience of agricultural communities facing environmental uncertainties.

The success of this program was also supported by multi-stakeholder collaboration involving universities, Perum BULOG, and farmer groups. Such partnerships demonstrate the importance of collaborative approaches in accelerating technology adoption and ensuring that innovations developed in academic environments can be practically implemented at the community level.

E. Sustainability and Future Development of Smart Mushroom House Systems

Although the implementation successfully introduced IoT-based cultivation management to KTP Alugoro, long-term sustainability depends on continuous system maintenance, stable internet connectivity, and the ability of farmers to independently manage technological components. Routine inspection of sensors, electrical connections, and communication networks is necessary to maintain system reliability.

The experience from KTP Alugoro provides an example of how appropriate digital technologies can be integrated into small-scale agricultural systems. Future development may include expanding automated control functions, integrating production data analysis, and applying similar systems to other climate-sensitive agricultural enterprises.

Overall, the IoT-based Smart Mushroom House intervention represents a practical approach for combining digital innovation, farmer empowerment, and climate adaptation strategies. The program demonstrates that technology adoption, when accompanied by participatory capacity building, can support the transformation of rural agribusiness toward a more resilient and sustainable production system.

Conclusion

The implementation of an IoT-based Smart Mushroom House system in the Alugoro Youth Farmer Group, Sragen Regency, successfully provided an adaptive solution for managing temperature and humidity conditions in oyster mushroom cultivation, particularly during the dry season. The integration of IoT technology enabled real-time environmental monitoring and automated irrigation control, allowing cultivation conditions to be maintained within the optimal range for oyster mushroom growth. The program also improved farmers' capacity to understand and operate digital agricultural technologies through participatory training and technology transfer activities.

The adoption of IoT-based cultivation management reduced dependence on conventional manual practices and supported more efficient and sustainable mushroom agribusiness management. This community engagement program demonstrates that combining appropriate technology with farmer empowerment can strengthen the resilience of small-scale agricultural systems against climate-related challenges. Future development should focus on improving system sustainability through routine maintenance, reliable connectivity, and broader adoption of smart farming technologies.

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enabling the successful application of IoT-based Smart Mushroom House technology as an adaptive solution for sustainable oyster mushroom cultivation.

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