

Community Service Implementation of IoT Water Quality Monitoring for Hydroponic Farming on Marginal Land

Diah Risqiwati^{1*}, Agus Eko Minarno¹, Bashor Fauzan Muthohirin¹, Ahmad Yuda Pratama², Fahrizal Irfanda Bagaskara², Varis Afdholin², Hanugra Aulia Sidharta³, Nova Eka Budiyanata⁴

¹Departement of Informatics, Universitas Muhammadiyah Malang, Indonesia 65144.

²Departement of Electrical Engineering, Universitas Muhammadiyah Malang, Indonesia 65144.

³Computer Science Departement, School of Computer Science, Bina Nusantara University, Indonesia 11530.

⁴Departement of Electrical Engineering, School of Bioscience Technology and Innovation, Universitas Katolik Indonesia Atma Jaya, Indonesia 15345

| Article Info | Abstract |
|--|--|
| <i>Article history:</i> Received 06 June 2026 Accepted 25 June 2026 <i>Keywords:</i> <i>aquaponics;</i> <i>hydroponics; Internet</i> <i>of Things; marginal</i> <i>land; water quality</i> <i>monitoring</i> | <p>This initiative implemented an integrated smart hydroponic–aquaponic system on marginal land in Bakalan Village, Bululawang District, Malang Regency, to support local food diversification and strengthen household food security. Although the village has strong agricultural potential, local production is still dominated by sugarcane, while vegetable needs are largely supplied from outside the village. To address this issue, the program developed a compact cultivation model that combines fish farming and hydroponic planting, supported by an Internet of Things (IoT)-based water quality monitoring system using ESP32 and wireless communication.</p> <p>The monitored parameters included total dissolved solids (TDS), water temperature, pH, turbidity, and humidity, and the collected data were stored in a local server that could be accessed through smartphones connected to the same network. The implementation results showed that the system was able to monitor water quality in real time and detect abnormal sensor readings, which were automatically recorded for further evaluation. Validated measurements indicated relatively stable operating conditions, with water temperature ranging from 26.8 to 27.1°C, pH from 7.1 to 7.7, ambient humidity from 76.8% to 78.7%, and TDS from 620 to 637 ppm. These findings suggest that the implementation of a smart hydroponic–aquaponic system can improve the productive use of marginal land, support more precise cultivation management, and contribute to community-based food security efforts.</p> |

1. INTRODUCTION

Bakalan Village, located in Bululawang District, Malang Regency, is an agricultural area whose economy is strongly supported by farming activities. Most residents work as farmers, planters, or livestock breeders, and sugarcane remains the dominant commodity because it has an established economic value and production chain. However, this agricultural pattern also creates a limitation in local food diversification, as household vegetable needs are still largely supplied from outside the village (Herlina, Wahyuni, Winahyu, Anwar, & Heliana, 2024). This condition indicates that improving local food security in Bakalan Village requires not only productive land use, but also cultivation models that can support food diversification without disrupting the existing sugarcane-based economy.

*Corresponding author. Diah Risqiwati
Email address: risqiwati@umm.ac.id

Initial discussions with village representatives identified an opportunity to utilize non-sugarcane land and less productive areas for alternative food production. One of the most relevant locations was the Bakalan Waste Bank area, where non-organic plastic waste is processed and where the surrounding land has relatively low suitability for conventional soil-based agriculture. In such conditions, hydroponic and aquaponic systems offer an appropriate solution because they are not highly dependent on soil fertility and can be implemented in limited or marginal spaces (Velazquez-Gonzalez, Garcia-Garcia, Ventura-Zapata, Barceinas-Sanchez, & Sosa-Savedra, 2022). Hydroponic cultivation has been recognized as a practical approach for improving vegetable production in constrained areas, while aquaponics extends this advantage by integrating fish cultivation and hydroponic planting in a recirculating system that improves nutrient and water use efficiency (Payen et al., 2022).

The relevance of this approach is supported by previous studies. Research on hydroponic food production has shown that hydroponics can strengthen household food security and improve access to fresh produce in settings with land limitations (Tessema & Dagne, 2024). In parallel, reviews on aquaponic systems emphasize that the integration of fish and plant cultivation can support sustainable food production, nutrient recycling, and circular resource use, making aquaponics particularly suitable for communities seeking efficient and adaptive farming models (Dahiya, Shweta, Kumar, Shubham, & Kaushal, 2025). These findings suggest that integrated hydroponic–aquaponic systems can serve not only as technical cultivation solutions, but also as community based strategies for strengthening local resilience (Espada Sanjurjo, Díaz de Mera-Sánchez, & Rodríguez Escudero, 2026).

In addition to cultivation design, water quality management is a critical factor in the success of hydroponic and aquaponic systems. Parameters such as pH, temperature, nutrient concentration, and turbidity influence nutrient availability, aquatic health, and the overall stability of the system (Pelayo, Castellanos, Ortega, Rojas, & Lengerke, 2025). Manual monitoring of these parameters is often time-consuming and difficult to maintain consistently in community settings. Therefore, the use of Internet of Things technology has become increasingly relevant in smart farming applications. Recent studies have demonstrated that ESP32-based monitoring systems are capable of recording key hydroponic parameters such as TDS, pH, water level, and temperature, while providing real-time access through smartphone-based interfaces (Abu Sneineh & Shabaneh, 2023). Other studies also report that ESP32-based monitoring and control in aquaponic systems can maintain high data transmission success and support accurate observation of pH and water temperature, which are essential for operational stability.

Based on this context, the present community service program implemented an integrated smart hydroponic–aquaponic system on marginal land in Bakalan Village. The system combined a fish pond, hydroponic pipes installed above the pond, and an ESP32-based IoT monitoring module to observe TDS, water temperature, pH, turbidity, and humidity. The collected data were transmitted through wireless communication and made accessible through a local smartphone-based interface, allowing users to monitor cultivation conditions in real time. Through this implementation, the program aimed to optimize marginal land use, support local food production, and introduce a practical model of digital agriculture that can be adopted and managed more independently by the community.

2. METHOD

2.1 Initial condition

At the early of the program, the partner had already owned a hydroponic installation that had previously been applied for vegetable cultivation. Nevertheless, the system was no longer in active use due to the failure of plant growth, which was indicated by plant desiccation and the inability of the cultivation system to sustain productive operation. This condition was presumably associated with excessive solar exposure, the absence of routine monitoring, and the lack of an appropriate mechanism for assessing water quality. As a consequence, the partner shifted to cultivation using polybags, while the existing hydroponic facility remained underutilized. In addition, limited knowledge regarding hydroponic maintenance and system upkeep further constrained the effective use of the installation. Based on these initial conditions, the activity was designed to introduce an automated water monitoring system and to extend the hydroponic setup into an aquaponic model as an adaptive strategy to optimize the partner's existing resources and improve the sustainability of cultivation practices.

2.2 System Design

The community service program employed an integrated hydroponic–aquaponic farming system designed to optimize the use of marginal land for food production. The physical layout consisted of a fish pond positioned as the primary water reservoir, with four hydroponic pipes installed above the pond to enable efficient vertical space utilization and nutrient circulation between aquaculture and plant cultivation components. This arrangement was selected to maximize land efficiency while supporting a compact and practical installation suitable for community implementation on limited or low-productivity land.

Hydroponic is functioned as the plant cultivation unit, while the aquaponic component contributed nutrient-rich water derived from fish cultivation activities. Through this integrated design, water circulated between the pond and hydroponic pipes, allowing the system to combine fish production and vegetable cultivation within a single operational framework. Such integrated systems are recognized for improving resource efficiency and supporting sustainable food production in constrained environments.

2.3 IoT Monitoring Architecture

Water quality monitoring was implemented using an ESP32 microcontroller configured as the main IoT sensing node. The system block diagram is shown in Figure 1. This device was responsible for acquiring sensor data and transmitting the readings wirelessly through a local network infrastructure. The ESP32 platform was selected because it supports embedded wireless communication, is widely used in low-cost environmental monitoring systems, and has been applied successfully in both hydroponic and aquaponic monitoring applications.

Data collected from multiple sensors representing the main operational variables of the integrated system. As shown in Table 1, onitored parameters included total dissolved solids (TDS), water temperature, pH, turbidity, and humidity. These parameters were selected because they reflect the quality of the water environment and the surrounding cultivation conditions, both of which directly influence plant growth performance and the stability of the aquaponic system.

Table 1.
Water quality sensor configuration

| <i>Parameter</i> | Type | Objective |
|-------------------|-------------------------|--|
| TDS | Analog TDS probe | Measures the concentration of dissolved solids in water, to indicate nutrient level in hydroponic systems. |
| Water temperature | DHT22 | Measures water temperature, which affects plant growth, nutrient uptake, and system stability. |
| pH | DF Robot (SEN0161) | Measures acidity or alkalinity of the water, which is important for maintaining suitable growing conditions. |
| Turbidity | Analog turbidity sensor | Measures water cloudiness and helps detect suspended particles or declining water quality. |

2.4 Monitored Parameters

The monitoring system was designed to observe five main parameters. TDS was used to estimate the concentration of dissolved nutrients in the water, which is essential in hydroponic cultivation because nutrient availability directly affects plant development. Water temperature was monitored because thermal stability influences both fish metabolism and nutrient solution conditions. The pH parameter was observed to evaluate acidity and alkalinity, which are critical for nutrient absorption and biological balance in integrated systems.

Turbidity was included to indicate water clarity and the presence of suspended particles that may affect both fish health and system cleanliness. Humidity was monitored to provide additional information about the ambient microclimate surrounding the cultivation area. Together, these variables provided a basic but representative description of the environmental and water quality conditions within the integrated hydroponic–aquaponic installation.

2.5 Data Communication

In addition to the sensing node, the system utilized a second ESP32 unit that functioned as a local server for data storage and access. After being collected by the sensing node, measurement data were transmitted wirelessly to the server ESP32, where they were stored and made available for monitoring purposes. This server architecture allowed the system to separate sensing and data management tasks, thereby improving modularity and enabling easier maintenance and future development.

The stored data could be accessed through a mobile phone connected to the same wireless network as the ESP32 server. In practical operation, users only needed to connect their smartphone to the local network in order to view the recorded monitoring data. This local-access approach was considered appropriate for community service implementation because it enabled low-cost digital monitoring without requiring continuous internet connectivity or paid cloud infrastructure, while still allowing users to observe system conditions in near real time.

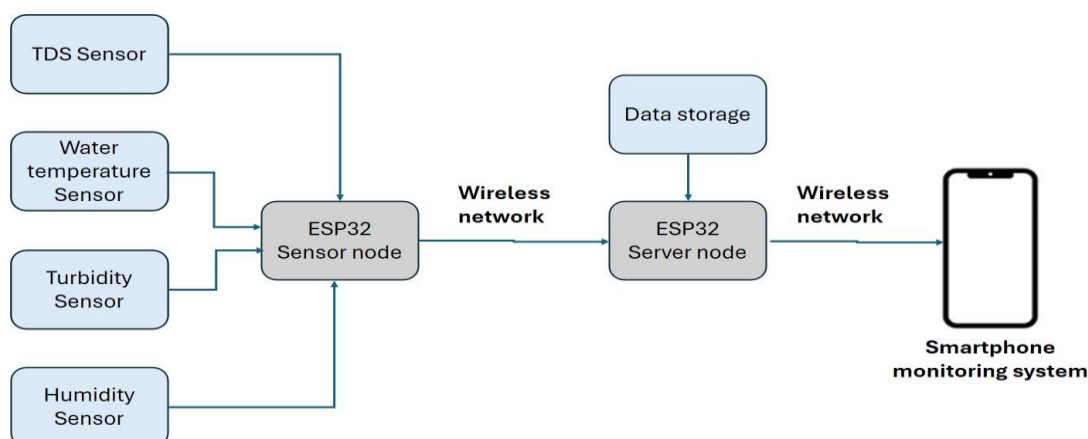


Figure 1.

System block diagram showing sensor acquisition, wireless communication, local data storage, and smartphone access.

2.6 Implementation Procedure

The implementation process was conducted in several stages. The first stage involved designing the integrated cultivation structure, including the placement of four hydroponic pipes above the fish pond and the preparation of water circulation pathways. The second stage involved installation of the sensor modules and integration of the sensors with the ESP32 sensing unit. The third stage involved configuration of wireless communication between the sensing ESP32 and the server ESP32, followed by testing of data transmission and local access through a smartphone device.

After installation, the system underwent functional testing to verify that each sensor could read and transmit data properly. The server ESP32 was then used as the local repository for storing monitoring records, while users accessed the data interface using mobile phones connected to the same network. Once the hardware and communication system were verified, the integrated cultivation unit was operated under normal conditions and the sensor readings were observed periodically to evaluate system functionality and data consistency.

2.7 Data Observation and Evaluation

The acquired monitoring data were evaluated descriptively to examine the stability of measured parameters and identify abnormal readings. Recorded variables such as water temperature, pH, TDS, turbidity, and humidity were reviewed as indicators of system condition during operation. Particular attention was given to unusual values that could reflect sensor disturbances, communication issues, or water quality changes requiring maintenance action.

This evaluation approach was appropriate for a community service setting because the primary objective was not only technical deployment but also practical usability and knowledge transfer. Therefore, the method emphasized system functionality, accessibility of monitoring data, and the usefulness of the measured parameters for supporting routine operation of the integrated hydroponic–aquaponic installation on marginal land.

3. RESULT AND DISCUSSION

3.1 System Implementation Results

The integrated hydroponic–aquaponic system was successfully installed on the target site, consisting of a fish pond combined with four hydroponic pipes positioned above the

pond, as shown in Figure 2. This arrangement enabled the use of vertical space and supported the application of a compact cultivation model suitable for marginal land utilization. The implementation also included the installation of an IoT monitoring system using ESP32 for sensor data acquisition and wireless communication, allowing environmental and water quality parameters to be observed in real time.

Hardware architecture functioned as intended during the implementation stage. The sensing unit collected data from multiple sensors and transmitted the readings wirelessly to a second ESP32 configured as a local server. The monitoring data could then be accessed through a smartphone connected to the same network, demonstrating that the system was not only operational but also practically usable for community monitoring activities.

As shown at Figure 3, implementation successfully combined an integrated hydroponic–aquaponic cultivation structure with an IoT-based monitoring system on marginal land. As shown in the field documentation, the hydroponic pipes were installed above the pond, while the sensor modules and ESP32 devices enabled real-time observation of water quality and environmental conditions, supporting practical and data-driven system operation.



Figure 2.

Hydroponic–aquaponic system implementation on marginal land, equipped with four pipe hydroponic and connected with fish pond through integrate pipe.

3.2 Monitoring data results

The monitoring system produced sequential data records containing air temperature, humidity, turbidity, TDS, water temperature, pH, anomaly count, and anomaly labels. Based on the available dataset, water temperature remained relatively stable within the range of 26.8–27.1°C, indicating that the aquatic environment was maintained under fairly consistent thermal conditions during the observation period.

Figure 3 shows the trend of sensor measurements recorded during system operation, including humidity, turbidity, TDS, water temperature, and pH. The data indicate that several parameters, particularly humidity and water temperature, remained relatively stable throughout the observation period, while TDS and pH exhibited several abnormal readings that may reflect temporary sensor disturbances or calibration issues. Overall, the monitoring system was able to capture multi-parameter environmental data and provide useful information for evaluating the operational condition of the integrated hydroponic-aquaponic system

The pH readings in the validated observations were generally recorded between 7.1 and 7.7, which indicates near-neutral to slightly alkaline water conditions. Such values suggest that, for most of the observation period, the system maintained an acceptable water condition for integrated cultivation activities, although further adjustment may still be required depending on the crop type and cultivation target.

TDS values in the valid records were observed in the range of 620–637 ppm. This result indicates that the nutrient concentration in the circulating water was relatively consistent during normal system operation. In addition, ambient humidity ranged from 76.8% to 78.7%, while air temperature was recorded between 27.2°C and 27.6°C, showing that the surrounding cultivation environment remained fairly stable throughout the monitoring session.

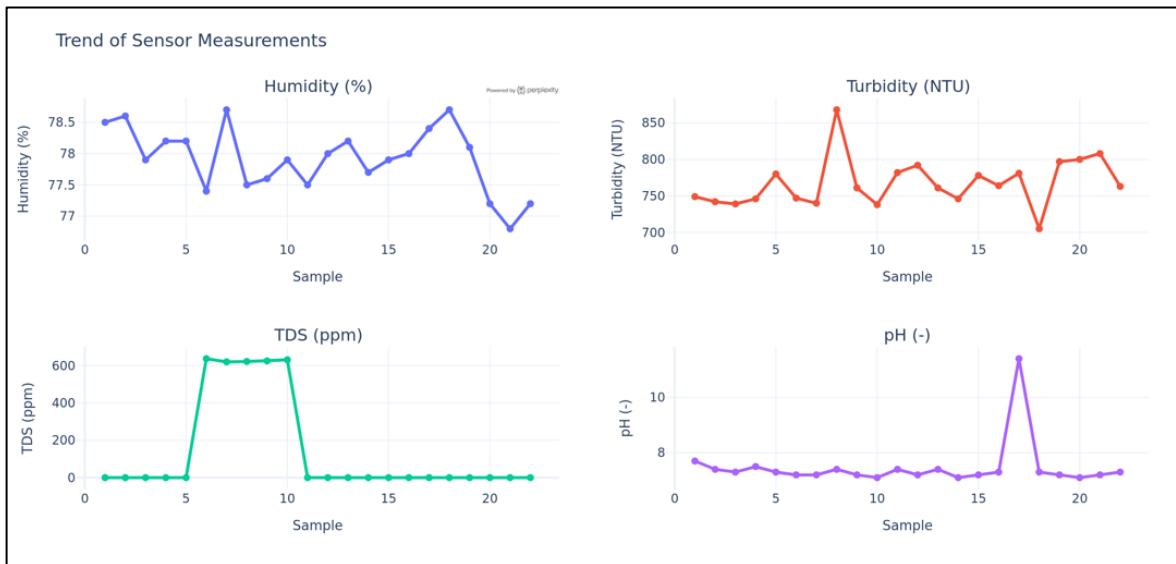


Figure 3.

Suasana pelaksanaan lokakarya pembuatan tempe: penyampaian materi (A) dan praktik langsung oleh peserta (B–D)

3.3 Anomaly Detection and Data Quality

One important result of the developed system was its ability to detect abnormal sensor readings and store anomaly information in the monitoring log. Several records showed a TDS value of 0, and one record showed a pH value of 11.4, both of which were inconsistent with the surrounding pattern of observations. These values indicate that the system was capable of identifying unusual readings that may have resulted from temporary sensor disturbance, calibration drift, or unstable sensor contact during operation.

The anomaly-related fields, namely *jmlanomali* and *sensoranomali*, provide an additional functional advantage because they allow users to distinguish between valid measurements and suspicious readings. In a community service context, this feature is particularly useful because it helps non-expert users recognize when maintenance, recalibration, or verification is needed before making operational decisions based on the data.

Thus, the monitoring system did not only perform data acquisition, but also contributed to basic data validation in the field. This capability improves the practical value of the system for routine use, especially in small-scale integrated farming where manual interpretation of raw sensor outputs may otherwise be difficult for community members.

Table 2 presents the descriptive statistics of the monitored parameters, showing the minimum, maximum, and mean values recorded during system operation. These values provide a concise overview of data stability and help identify parameters that deviated from the normal range, thereby supporting the discussion on anomaly detection and overall data quality.

Table 2.

Descriptive statistics of monitored environmental and water quality parameters.

| <i>Parameter</i> | Min | Max | Mean |
|------------------|-------|-------|--------|
| Humidity (%) | 76.8 | 78.7 | 77.91 |
| Turbidity (NTU) | 705.0 | 868.0 | 767.59 |
| TDS (ppm) | 0.0 | 637.0 | 142.5 |
| ph | 7.1 | 11.4 | 7.47 |

3.4 Benefits for Community

The implementation results suggest that the developed system can support more structured and data-informed management of hydroponic–aquaponic cultivation on marginal land. Through real-time monitoring, users are able to observe the condition of the water and surrounding environment without relying solely on manual inspection. This is beneficial for improving operational awareness and for reducing the risk of unnoticed environmental changes that may affect plant or fish growth.

In addition, the use of a local wireless server made the system accessible through a smartphone without requiring internet cloud services. This configuration is appropriate for community-level application because it reduces infrastructure dependency while still providing digital access to monitoring results. As a result, the system offers both technological functionality and practical usability for local empowerment and knowledge transfer activities.

3.5 Key important findings

The recorded data indicate that the system was able to maintain stable monitoring performance for several core parameters, particularly water temperature, humidity, and validated pH and TDS values. These results reflect that the integrated cultivation environment operated under generally controlled conditions during the observation period.

At the same time, the presence of anomalous readings demonstrates that sensor monitoring systems require routine validation and maintenance. Rather than being treated solely as a limitation, this finding can be discussed as evidence that the developed monitoring architecture was capable of recognizing irregularities in the data, which is an important feature for practical deployment in real cultivation settings.

Overall, the results show that the integrated hydroponic–aquaponic system, combined with ESP32 wireless monitoring, was successfully implemented and functioned as intended. The system was able to support environmental monitoring, provide accessible local data services, and contribute to the productive use of marginal land through technology-assisted cultivation practices.

4. CONCLUSION

This community service activity successfully implemented an integrated hydroponic–aquaponic cultivation system equipped with an IoT-based water quality monitoring module on marginal land. The developed system was able to support real-time observation of several

key parameters, including water temperature, pH, TDS, turbidity, and ambient humidity, while also enabling local data access through a wireless network and smartphone interface. The recorded data showed relatively stable conditions in several validated measurements, particularly water temperature in the range of 26.8–27.1°C, pH in the range of 7.1–7.7, ambient humidity in the range of 76.8–78.7%, and TDS in the range of 620–637 ppm. These results indicate that the implemented system functioned properly and provided useful technical information for supporting routine operation of the integrated cultivation unit.

In addition to its technical function, the program demonstrated that the use of IoT technology can improve the practical utilization of marginal land through more structured and data-driven cultivation management. The combination of cultivation infrastructure, wireless monitoring, and community involvement contributed not only to system operation but also to knowledge transfer and digital capacity building among users. Therefore, the activity shows that integrated hydroponic–aquaponic farming supported by IoT monitoring has strong potential to contribute to local food production and more adaptive community-based farming practices on limited or low-productivity land.

Several recommendations can be proposed to improve the sustainability and technical performance of the system. First, routine sensor calibration and maintenance should be conducted to reduce abnormal readings, particularly for parameters that showed anomalies such as TDS and pH. Second, future development may include the addition of other relevant parameters, such as dissolved oxygen, water level, and light intensity, in order to provide a more comprehensive representation of system conditions.

5. ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Universitas Muhammadiyah Malang for providing financial support through the Blockgrant Pemberdayaan Kemitraan Masyarakat (PKM) 2025. The authors also extend their appreciation to the community partners in Desa Bakalan, Bululawang, Kabupaten Malang, for their active participation, cooperation, and support throughout the implementation of the IoT-based integrated farming system.

6. REFERENCES

1. Abu Sneineh, A., & Shabaneh, A. A. A. (2023). Design of a smart hydroponics monitoring system using an ESP32 microcontroller and the Internet of Things. *MethodsX*, 11, 102401. <https://doi.org/10.1016/j.mex.2023.102401>
2. Dahiya, U., Shweta, Kumar, M., Shubham, & Kaushal, S. (2025). Revolutionizing Agriculture: Exploring the Potential of Hydroponics for Global Food Security. *European Journal of Nutrition & Food Safety*, 17(4), 302–316. <https://doi.org/10.9734/ejnfs/2025/v17i41701>
3. Espada Sanjurjo, J. J., Díaz de Mera-Sánchez, M. P., & Rodríguez Escudero, R. (2026). Design and Environmental Analysis of an Aquaponics System Coupled with Photovoltaic Unit for Food Production and Reuse of Nutrients from Wastewater: A Life Cycle Assessment Study. *Applied Sciences*, 16(2), 635. <https://doi.org/10.3390/app16020635>
4. Herlina, N., Wahyuni, H., Winahyu, F. P., Anwar, K., & Heliana. (2024). The Movement to Maintain Food Security Through Technological Advancements and Local Diversification: Ministry of Agriculture Republic of Indonesia. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan*, 14(3), 555–565. <https://doi.org/10.29244/jpsl.14.3.555>

5. Payen, F. T., Evans, D. L., Falagán, N., Hardman, C. A., Kourmpetli, S., Liu, L., ... Davies, J. A. C. (2022). How Much Food Can We Grow in Urban Areas? Food Production and Crop Yields of Urban Agriculture: A Meta-Analysis. *Earth's Future*, 10(8), 1–22. <https://doi.org/10.1029/2022EF002748>
6. Pelayo, J. S. F., Castellanos, L. S. M., Ortega, R. C., Rojas, L. G. H., & Lengerke, O. (2025). Smart water quality regulation in sustainable aquaponics using PID control and long-term performance analysis. *Sustainable Engineering and Innovation*, 7(2), 521–536. <https://doi.org/10.37868/sei.v7i2.id606>
7. Tessema, L., & Dagne, Z. (2024). *Perspective Chapter: Hydroponic Farming for Food and Nutrition Security – Challenges and Prospects*. <https://doi.org/10.5772/intechopen.1007946>
8. Velazquez-Gonzalez, R. S., Garcia-Garcia, A. L., Ventura-Zapata, E., Barceinas-Sanchez, J. D. O., & Sosa-Savedra, J. C. (2022). A Review on Hydroponics and the Technologies Associated for Medium-and Small-Scale Operations. *Agriculture (Switzerland)*, 12(5), 1–21. <https://doi.org/10.3390/agriculture12050646>