IoT-Based Real-Time Monitoring of Hydroponic Systems for Caisim (*Brassica juncea*) with Spreadsheet Integration

Algifari A. Pilanto, Alfian Ma'arif *, Muhammad Haryo Setiawan
Electrical Engineering, Universitas Ahmad Dahlan
*Corresponding Author

ARTICLE INFO

Article history:

Received December 02, 2024
Revised December 30, 2024
Published January 14, 2025

Keywords:

Hydroponics;
Real-Time Monitoring;
Caisin (*Brassica junceai*);
Spreadsheet Integration

ABSTRACT

This research investigates the integration of Internet of Things (IoT) technology and spreadsheet databases to enhance real-time monitoring and control of a hydroponic system, specifically for the cultivation of Caisim (*Brassica juncea*). The system utilizes an ESP32 microcontroller and DHT22 sensors to monitor temperature and humidity, transmitting data to a Google Sheets spreadsheet for real-time analysis. The hydroponic setup consists of a multi-level nutrient circulation system, ensuring optimal nutrient supply to the plants. The results demonstrate the effectiveness of the system in maintaining ideal environmental conditions, resulting in robust plant growth. Over a 30-day period, the caisim plants achieved a height of 27 cm, produced nine leaves, and exhibited a leaf width of 9.4 cm. The use of spreadsheets for data logging allows for detailed trend analysis and timely adjustments, offering a more efficient and precise approach compared to traditional monitoring methods. Future enhancements could include the integration of additional sensors for monitoring pH levels and the development of an interactive dashboard for enhanced user experience and system optimization.

Cite Article:

A. A. Pilanto, A. Ma'arif, and M. H. Setiawan, "IoT-Based Real-Time Monitoring of Hydroponic Systems for Caisim (Brassica juncea) with Spreadsheet Integration," *Journal of Science in Agrotechnology*, vol. 1, no. 2, pp. 89-98, 2023, doi: 10.21107/jsa.v1i2.19.

1. INTRODUCTION

Hydroponics, a soil-free plant cultivation technique [1], is gaining popularity worldwide for its efficient use of resources and suitability in areas with limited land availability [2]. In hydroponic systems, plants are grown in a non-soil medium and supplied with a nutrient-rich solution containing essential elements for growth [3], [4]. This method offers numerous advantages, including efficient water usage [5], [6], improved environmental control [7], and higher crop yields per unit area compared to traditional farming methods also lower production costs and have a higher benefit ratio [8]. These benefits make hydroponics a promising solution for addressing global food security challenges in an increasingly urbanized world.

However, traditional measurement tools often present challenges, particularly in transmitting data in real-time for online monitoring and in-depth analysis. The limited functionality of these tools can hinder continuous monitoring, making it difficult to detect issues in a timely manner and react accordingly [9]. For commercial and research-oriented hydroponic setups, these limitations can reduce operational efficiency and impact the system's overall effectiveness. Therefore, advanced monitoring solutions that offer real-time data accessibility are increasingly in demand.

Integrating Internet of Things (IoT) technology into hydroponic systems can significantly improve the effectiveness and responsiveness of monitoring efforts. IoT enables the connection of various sensors to an online platform [10], allowing data to be collected, transmitted, and accessed remotely in real-time [11]. This connectivity means that crucial data about the hydroponic system's status is always available to users through web or mobile applications, making it easier to monitor and maintain optimal conditions even when not physically present.

Sadi, Sumardi, et al., (2021) [12] focused on the development of an IoT-based system for the remote monitoring of hydrogenic plants and fish ponds, utilizing Arduino Mega and Uno integrated with the Thingspeak cloud platform. The system employs an ESP-01 Wi-Fi module to facilitate real-time data tracking via the Thingspeak server, enabling users to monitor various parameters through a smartphone or PC connected to the internet. Key components include ultrasonic sensors for measuring water and fish feed levels, a DHT11 sensor for monitoring temperature and humidity, a soil moisture sensor, a servo motor for automating fish feeding, an aquarium pump, and a cooling fan. Data transfer from the Arduino to Thingspeak occurs approximately every 15 seconds, allowing for up to 240 data points per hour, which can be downloaded in Excel format. This approach provides users with a comprehensive view of environmental conditions, simplifies the monitoring process, and enhances agricultural productivity. While the system effectively demonstrates accuracy in sensor readings and reliable data transmission, the use of two microcontrollers may be considered redundant. Future improvements could focus on streamlining the hardware to utilize a single, more powerful microcontroller, thereby reducing material costs and improving overall efficiency.

Khairulnizam et al., (2021) [13] designed and implemented an IoT-based monitoring and control system for a hydroponic setup to optimize the growth of Chinese kale. Using a NodeMCU microcontroller, the system monitored and controlled parameters such as temperature, humidity, and lighting. Data were collected and stored in the ThingSpeak cloud, while the Blynk app allowed remote monitoring and control via smartphones. The controlled system, which maintained optimal temperature (25-28°C) and provided 16 hours of light daily, resulted in significantly larger and healthier plant growth compared to an uncontrolled system. The study demonstrated that IoT integration can enhance plant growth rates and reduce farmers' workload by automating environmental control.

This research project aims to investigate the potential applications of sensor technology in a hydroponic system integrated with the IoT, with a specific focus on enhancing responsiveness and reducing data latency in real-time monitoring. To facilitate effective data analysis, the collected data will be organised in a spreadsheet format, allowing users to analyse trends, generate reports and make informed decisions. The prototype will be compared against existing solutions such as ThingSpeak to evaluate its performance in terms of responsiveness, thereby providing a comprehensive solution for real-time monitoring of critical parameters. This integration of data management will contribute to a more efficient and productive hydroponic farming process.

2. METHODS

2.1. Hydroponics

Hydroponics is a soil-less plant cultivation method in which nutrient solutions composed of water and essential minerals are used to promote plant growth [14]. The core principle of hydroponics involves delivering the necessary nutritional elements directly to the plant roots through a carefully regulated solution, allowing plants to thrive even in a restricted, soil-less environment [15], [16], [17].

In hydroponic systems, plants are placed in a non-aquatic medium, such as rockwool [18], perlite [19], vermiculite [20], or coconut fiber [21], which serves a dual purpose as a physical support and a moisture-absorbing medium. The nutrient solution contains essential elements, including nitrogen [22], phosphorus [23], potassium [24], calcium [25], magnesium [26], and other micronutrients [27], which are required by plants for photosynthesis, growth, and development. The concentration of nutrients in the solution is regulated in order to ensure optimal availability for the plants.

Hydroponics offers a number of advantages over conventional cultivation methods. These include more efficient water use [28], a reduced risk of soil-borne plant diseases [29], and an increased yield per unit area [30]. Additionally, hydroponic systems make it possible to cultivate plants in locations unsuitable for conventional farming, such as urban environments or regions with poor soil quality. Thus, hydroponics serves as an innovative solution to increase food production, particularly in controlled environments, making it a valuable alternative to traditional agricultural practices. Fig. 1, shows the Hydroponics system design.

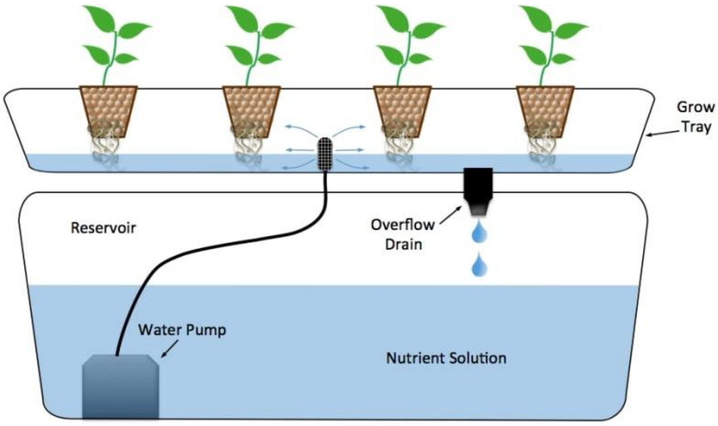


Fig. 1. Hydroponics system design

2.2. Caisim (*Brassica juncea*)

Caisim (*Brassica juncea*), also known as mustard greens, is a member of the Brassicaceae family of plants. It is commonly recognized for its broad, dark green leaves, crisp texture, and distinctive flavor. This plant is capable of thriving in a variety of soil types, particularly those that are fertile and retain adequate moisture, thereby making it suitable for diverse agricultural conditions. The antioxidants present in caisim contribute to the protection of cells against damage caused by free radicals, thereby supporting immune function and overall health [31].

2.3. System Design

This section presents the design framework for the hydroponic monitoring and control system integrated with the Internet of Things (IoT). The system design focuses on developing a structure that effectively manages sensor data collection, data processing, and response mechanisms to optimize plant growth conditions. The design includes three main components: the block diagram, flowchart, and wiring diagram, each providing a different perspective on the system's architecture and operation.

2.3.1. Block Diagram

The block diagram provides an overview of the overall architecture of the hydroponic system, illustrating the primary components and their interactions. It offers a high-level view of the system's operational components, including sensors, microcontrollers, power sources, and IoT communication modules. Each component's function and connectivity are outlined, facilitating a comprehensive understanding of the data flow and control processes essential for system operation. Fig. 2 shows the block diagram system.

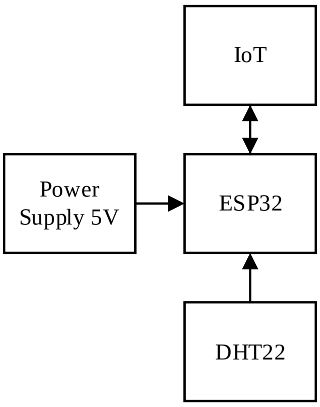


Fig. 2. Block diagram system

Fig. 2 illustrates the system's utilization of DHT22 sensors to quantify the temperature and humidity of the hydroponic environment. Subsequently, the data is transmitted to the ESP32 microcontroller via Wi-Fi for real-time monitoring in Google Sheets. The ESP32 microcontroller, which is connected to a 5 V mains power source, processes the data from the sensors at regular intervals and transmits it to a cloud server for storage and subsequent analysis. The system ensures efficient and stable environmental monitoring with reliable power source support.

2.3.2. Flowchart

The flowchart represents a step-by-step visual representation of the system's operational process. It provides a detailed account of the sequence of actions performed by the system, from initial sensor data collection to decision-making processes and actuations. By following the flowchart, users can gain insight into the logical flow of the monitoring and control functions, including the conditions for activating alerts or adjusting nutrient solutions based on real-time sensor readings. Fig. 3 shows the flowchart system

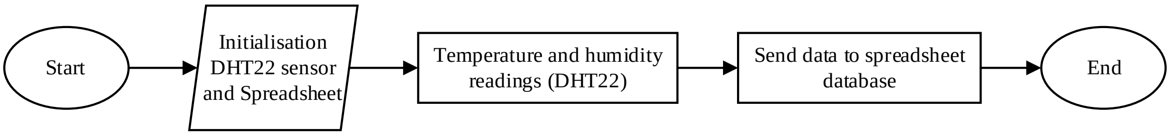


Fig. 3. Flowchart system

Fig. 3 presents a flowchart of the operational procedure of the temperature and humidity monitoring system, which employs the DHT22 sensor and ESP32 microcontroller. The process begins with the initialization of the DHT22 sensor and its connection to Google Sheets, thereby ensuring that the device is prepared to collect and transmit data. Subsequently, the DHT22 sensor acquires the temperature and humidity data, which are then conveyed to the Spreadsheet database for real-time storage and monitoring. Once this transmission is complete, the system is prepared to commence the monitoring cycle anew.

2.3.3. Wiring Diagram

The wiring diagram provides a detailed representation of the physical connections between the system components, illustrating the wiring configuration of each sensor, microcontroller, and actuator within the circuit. This diagram serves as a practical guide for assembling the system, ensuring that each connection aligns with the design requirements for reliable and safe operation. The wiring diagram is a crucial reference for both initial setup and troubleshooting, providing precise information for correct assembly and maintenance. Fig. 4 shows the Wiring Diagram and Table 1 show the pin configuration.

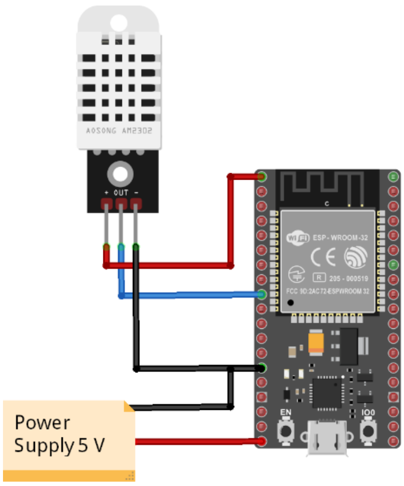


Fig. 4. Wiring diagram

Table 1. Pin configuration and power connections for ESP32 and DHT22 sensor integration

Initial Device		**Target Device**	
Device Name	PIN	Device Name	PIN
ESP32	GPIO25	DHT22	OUT
ESP32	3V3	DHT22	VCC
ESP32	GND	DHT22	GND
Power Supply	5V	ESP32	VIN
Power Supply	GND	ESP32	GND

Fig. 4 and Table 1 details the requisite connections for integrating an ESP32 microcontroller with a DHT22 sensor, in conjunction with an external power supply, for optimal operational stability. The ESP32's GPIO25 pin is connected to the OUT pin of the DHT22 sensor, thus enabling the microcontroller to receive digital signals carrying temperature and humidity data. The DHT22 is powered by the ESP32's 3.3V output (3V3), which is connected to the sensor's VCC pin. Additionally, both devices share a common ground through their GND pins. Furthermore, the ESP32 is supplied with a 5V external power source connected to its VIN pin, with the ground of the power supply connected to the ESP32's GND. This configuration ensures that both the sensor and microcontroller receive consistent power and share a stable reference voltage, enabling accurate data transmission from the DHT22 to the ESP32.

3. RESULTS AND DISCUSSION

The Internet of Things (IoT) can be defined as a network of physical objects that are connected to the internet and can communicate with each other. These objects, often referred to as "smart devices," are equipped with sensors, hardware, and software that enable them to collect, send, and receive data. The primary benefits of IoT in agriculture include the ability to monitor and control the environment in real-time.

3.1. Hardware Implementation

This research successfully developed a hydroponic system monitoring device, Fig. 5 shows the final results of the system developed in this research.

Fig. 5. System results

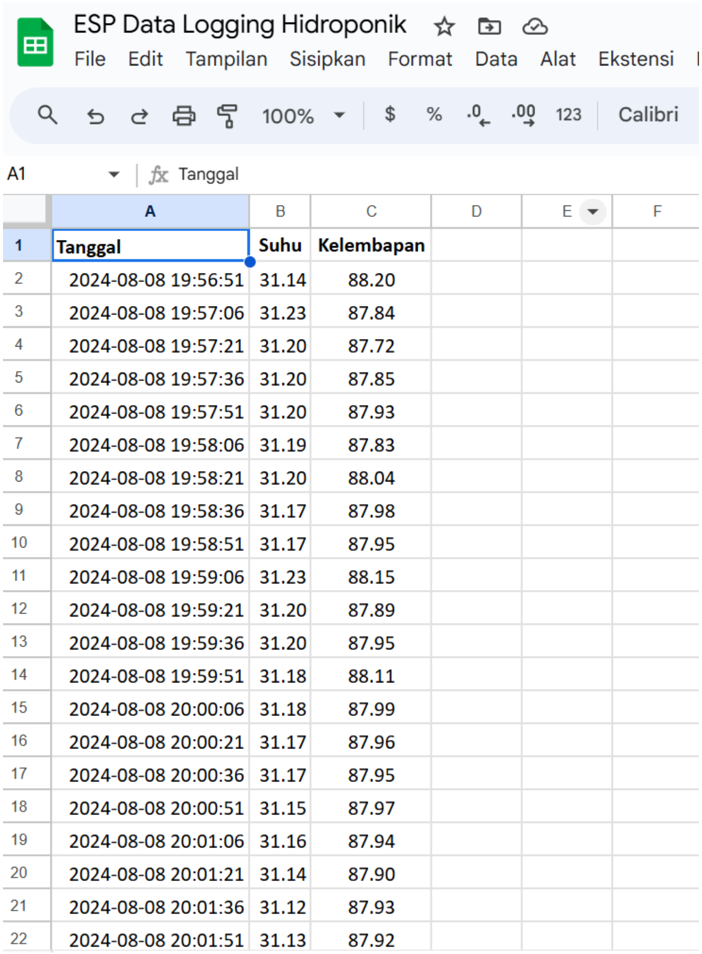
Fig. 5 displays the design of the hydroponic system, which features nine net pot holes arranged across three levels, with each level containing three net pot holes. The nutrient tank is situated at the lowest point of the system, and the nutrient water flow originates from this tank and is conveyed to the uppermost level. From there, the nutrient solution flows downward by gravity to the second level, then to the third level, and finally returns to the nutrient tank. This continuous circulation process ensures the optimal supply of nutrients for plant growth.

3.2. Monitoring System

This section presents an overview of the monitoring interface displayed in the spreadsheet, which is designed to organize and present environmental data in a clear, time-structured format. Fig. 6 illustrates the layout of this monitoring system, which captures and logs key parameters such as temperature and humidity over time. The spreadsheet provides a user-friendly view that allows users to track and analyze environmental changes, supporting informed decisions and timely adjustments based on observed trends.

Based on Fig. 6, the initial column of the table presents comprehensive temporal data, encompassing the year, month, date, and hour of the measurement. The provision of temporal context through time information is significant, as it enables users to track changes in temperature and humidity over time. The second column presents the temperature data in Celsius, a standard unit widely used in scientific and technical contexts, facilitating the analysis and interpretation of the data. This temperature data, obtained from sensors, provides insights into the environmental conditions. The third column displays humidity information in percent, reflecting the amount of water vapor in the air—an important parameter affecting factors like plant health, human comfort, and drying processes. The table structure allows users to understand the relationship between time, temperature, and humidity and to analyze patterns and trends in the data.

The use of a spreadsheet offers several advantages over platforms like ThingSpeak, particularly when implemented through a web-based platform. Unlike ThingSpeak, which has a data collection interval from 15 seconds at its fastest [32], [33], [34], [35], a spreadsheet allows data acquisition every 2 seconds, enabling finer-grained monitoring and more detailed tracking of environmental changes. Furthermore, a web-based spreadsheet provides a flexible and customizable interface, allowing users to adapt the data presentation to suit specific needs. This flexibility, combined with the faster data collection interval, makes spreadsheets especially useful for applications requiring real-time or near-real-time data analysis.



Tanggal	Suhu	Kelembapan
2024-08-08 19:56:51	31.14	88.20
2024-08-08 19:57:06	31.23	87.84
2024-08-08 19:57:21	31.20	87.72
2024-08-08 19:57:36	31.20	87.85
2024-08-08 19:57:51	31.20	87.93
2024-08-08 19:58:06	31.19	87.83
2024-08-08 19:58:21	31.20	88.04
2024-08-08 19:58:36	31.17	87.98
2024-08-08 19:58:51	31.17	87.95
2024-08-08 19:59:06	31.23	88.15
2024-08-08 19:59:21	31.20	87.89
2024-08-08 19:59:36	31.20	87.95
2024-08-08 19:59:51	31.18	88.11
2024-08-08 20:00:06	31.18	87.99
2024-08-08 20:00:21	31.17	87.96
2024-08-08 20:00:36	31.17	87.95
2024-08-08 20:00:51	31.15	87.97
2024-08-08 20:01:06	31.16	87.94
2024-08-08 20:01:21	31.14	87.90
2024-08-08 20:01:36	31.12	87.93
2024-08-08 20:01:51	31.13	87.92

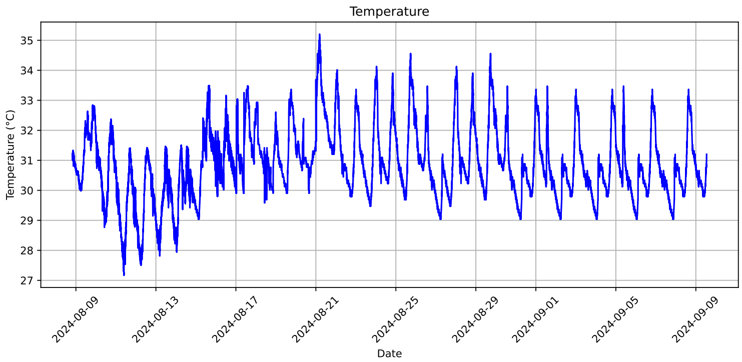
Fig. 6. Monitoring spreadsheet (Tanggal means date, suhu means temperature, and kelembapan means humidity)

3.3. Plant Growth Results

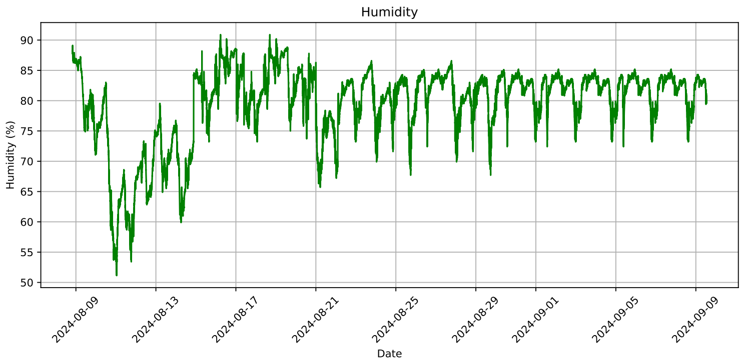
In this research, *Brassica juncea* (caisim) was cultivated following a 7-day germination period, after which the seedlings were transferred to a hydroponic system for further growth. The harvest results of the plants are depicted in Fig. 7.

Fig. 7. Caisim plant harvest results

Throughout the cultivation period, environmental conditions, including temperature and humidity, were meticulously monitored using a spreadsheet, as illustrated in Fig. 8. This data encompasses a comprehensive 30-day growth cycle for caisim, providing valuable insights into the plant's development in the hydroponic system.



(a)



(b)

Fig. 8. Monitoring results (a) Temperature, (b) Humidity in hydroponic system

As illustrated in Fig. 8(a), the mean temperature recorded during the cultivation period was 30.89°C, with a minimum temperature of 27.17°C and a maximum of 35.20°C. These temperature ranges are critical for optimizing plant growth, as they directly influence physiological processes. Fig. 8(b) presents the humidity levels, where the average was 81.36%. The humidity fluctuated between a minimum of 51.13% and a maximum of 90.9%, highlighting the variability in environmental conditions that can affect plant health and development.

Table 2 provides a detailed account of the growth progression of caisim in the hydroponic system. This table includes essential metrics such as plant height (cm), leaf count (number of leaves), and leaf width (cm), recorded daily throughout the observation period. The data illustrate the correlation between environmental conditions and growth outcomes, underscoring the efficacy of the hydroponic system in fostering optimal conditions for caisim cultivation. Overall, the results demonstrate that the hydroponic method successfully supported the growth of caisim, emphasizing its potential as a viable agricultural technique for producing nutritious crops.

Table 2. Growth of plant over 30 days

Days-	Plant height (cm)	Number of leaves (leaflets)	Leaf width (cm)
5	5	4	1.7
10	11	5	2.6
15	16	7	4.8
20	19	7	6.3
25	24	8	7.8
30	27	9	9.4

Table 2 presents the growth data for *Brassica juncea* (caisim) over a 30-day period, which includes key metrics such as plant height, number of leaves, and leaf width. The data provide insight into the developmental patterns of caisim when grown in a hydroponic system, thereby highlighting the impact of environmental conditions on plant growth.

On day five, the mean plant height was recorded at 5 cm, with an average of 4 leaves and a leaf width of 1.7 cm. These initial measurements indicate the establishment phase of the plants, during which the seedlings are acclimating to their environment. By day 10, a notable increase in growth was observed, with the plant height increasing to 11 cm, the number of leaves increasing to 5, and a significant increase in leaf width to 2.6 cm. This rapid growth in the early stages indicates that the hydroponic conditions were conducive to the initial development of the plants.

As the growth period continued, from day 15 to day 30, there were consistent increases in plant height, leaf number, and leaf width. On day 15, the plants reached an average height of 16 cm, with an average of 7 leaves and a leaf width of 4.8 cm. The growth rate continued to accelerate, with plant heights of 19 cm and 24 cm being recorded on days 20 and 25, respectively. This consistent increase indicated that the plants were responding favorably to the nutrient solution and the environmental factors within the hydroponic system.

By day 30, the plants had reached an impressive height of 27 cm with a total of 9 leaves and a leaf width of 9.4 cm. These data demonstrate the efficacy of the hydroponic approach in facilitating robust growth and development. The increase in leaf number and width indicates that the plants were not only maturing in height, but also expanding their photosynthetic capacity, which is essential for optimal growth and yield.

4. CONCLUSION

The design and implementation of the hydroponic system have successfully cultivated *Brassica juncea* (caisim) and demonstrated effective monitoring capabilities through a spreadsheet interface. The system provides an optimal environment for plant growth while facilitating real-time data recording. The use of spreadsheets for data collection enables a much higher data acquisition rate of 2 seconds per reading, compared to the 15-second interval provided by platforms like ThingSpeak. This more detailed monitoring allows for tracking environmental changes and identifying key factors influencing plant development, thus supporting more precise nutrient management strategies. The caisim plants cultivated using this hydroponic system achieved a height of 27 cm, which is 15% higher than average growth reported in similar studies using conventional hydroponic systems.

In future research, more focus could be placed on integrating automated sensors to monitor key environmental factors like temperature, humidity, and pH in real-time. This would help ensure timely adjustments to maintain optimal growing conditions and improve nutrient management. Additionally, incorporating IoT technology with web-based platforms connected to spreadsheets could streamline data collection from multiple sensors, making critical information more accessible. An interactive dashboard could visualize plant growth and environmental data, while notification systems could alert users to any conditions that exceed predefined thresholds. Future studies may also explore the use of AI-driven predictive analytics to optimize nutrient delivery based on real-time data, further enhancing plant growth efficiency and reducing resource waste. By pursuing these approaches, hydroponic systems can become more responsive, sustainable, and productive in the long term.

Author Contribution

All authors contributed equally to the main contributor to this paper. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

[1] S. Ranganathapura Sathyanarayana, W. Vishal Gangadhar, M. Girish. Badrinath, R. Manish. Ravindra, and A. Uday. Shriramrao, "Hydroponics: An Intensified Agriculture Practice to Improve Food Production," *Reviews in Agricultural Science*, vol. 10, pp. 101–114, 2022.

[2] S. R. Sathyanarayan, V. G. Warke, G. B. Mahajan, and U. S. Annapure, "Soil free nutrient availability to plants," *J Plant Nutr*, vol. 46, no. 5, pp. 801–814, Mar. 2023.

[3] D. J. Gaikwad, "Hydroponics Cultivation of Crops," in *Protected Cultivation and Smart Agriculture*, New Delhi Publishers, 2020.

[4] S. Khan, A. Purohit, and N. Vadsaria, "Hydroponics: current and future state of the art in farming," *J Plant Nutr*, vol. 44, no. 10, pp. 1515–1538, Jun. 2021.

[5] N. A. Elmulthum *et al.*, "Water Use Efficiency and Economic Evaluation of the Hydroponic versus Conventional Cultivation Systems for Green Fodder Production in Saudi Arabia," *Sustainability*, vol. 15, no. 1, p. 822, Jan. 2023.

[6] R. D. la Rosa-Rodríguez, A. Lara-Herrera, L. I. Trejo-Téllez, L. E. Padilla-Bernal, L. O. Solis-Sánchez, and J. M. Ortiz-Rodríguez, "Water and fertilizers use efficiency in two hydroponic systems for tomato production," *Hortic Bras*, vol. 38, no. 1, pp. 47–52, Jan. 2020.

[7] K. J. Walters, B. K. Behe, C. J. Currey, and R. G. Lopez, "Historical, Current, and Future Perspectives for Controlled Environment Hydroponic Food Crop Production in the United States," *HortScience*, vol. 55, no. 6, pp. 758–767, Jun. 2020.

[8] M. Majid, J. N. Khan, Q. M. Ahmad Shah, K. Z. Masoodi, B. Afroza, and S. Parvaze, "Evaluation of hydroponic systems for the cultivation of Lettuce (Lactuca sativa L., var. Longifolia) and comparison with protected soil-based cultivation," *Agric Water Manag*, vol. 245, p. 106572, Feb. 2021.

[9] A. S. Rao *et al.*, "Real-time monitoring of construction sites: Sensors, methods, and applications," *Autom Constr*, vol. 136, p. 104099, Apr. 2022.

[10] E. N. Aba, O. A. Olugboji, A. Nasir, M. A. Olutoye, and O. Adedipe, "Petroleum pipeline monitoring using an internet of things (IoT) platform," *SN Appl Sci*, vol. 3, no. 2, p. 180, Feb. 2021.

[11] L. Babun, K. Denney, Z. B. Celik, P. McDaniel, and A. S. Uluagac, "A survey on IoT platforms: Communication, security, and privacy perspectives," *Computer Networks*, vol. 192, p. 108040, Jun. 2021.

[12] S. Sadi, S. Mulyati, and I. K. Wijaya, "The Use of the Internet of Things in the Design and Construction of a Monitoring System for Hydrogenic Plants and Fish Ponds Using Thingspeak And Esp-01," *Journal of Research in Construction, Communication, and Commercial*, vol. 1, no. 1, 2020.

[13] K. Ngadimon, S. M. Basharie, K. Othman, and T. A. / L. Raman, "Lighting and Air Temperature Monitoring and Control of Hydroponic System using Internet of Things (IoT)," *Multidisciplinary Applied Research and Innovation*, vol. 2, no. 1, pp. 266–276, 2021.

[14] Y. V. Bhargava, P. K. Chittoor, C. Bharatiraja, R. Verma, and K. Sathiyasekar, "Sensor Fusion Based Intelligent Hydroponic Farming and Nursing System," *IEEE Sens J*, vol. 22, no. 14, pp. 14584–14591, Jul. 2022.

[15] M. Ali Al Meselmani, "Nutrient Solution for Hydroponics," in *Recent Research and Advances in Soilless Culture*, IntechOpen, 2023.

[16] A. Miller, R. Adhikari, and K. Nemali, "Recycling Nutrient Solution Can Reduce Growth Due to Nutrient Deficiencies in Hydroponic Production," *Front Plant Sci*, vol. 11, Dec. 2020.

[17] A. A. Stegelmeier, D. M. Rose, B. R. Joris, and B. R. Glick, "The Use of PGPB to Promote Plant Hydroponic Growth," *Plants*, vol. 11, no. 20, p. 2783, Oct. 2022.

[18] M. Komorowska *et al.*, "Evaluation of Sheep Wool as a Substrate for Hydroponic Cucumber Cultivation," *Agriculture*, vol. 13, no. 3, p. 554, Feb. 2023.

[19] S. G. Maxineasa, D. N. Isopescu, M. L. Lupu, I.-R. Baciu, L. Pruna, and C. Somacescu, "The use of perlite in civil engineering applications," *IOP Conf Ser Mater Sci Eng*, vol. 1242, no. 1, p. 012022, Apr. 2022.

[20] R. Łaźny *et al.*, "Effect of Re-Used Lignite and Mineral Wool Growing Mats on Plant Growth, Yield and Fruit Quality of Cucumber and Physical Parameters of Substrates in Hydroponic Cultivation," *Agronomy*, vol. 11, no. 5, p. 998, May 2021.

[21] I. Kremenetskaya *et al.*, "Physicochemical transformation of expanded vermiculite after long-term use in hydroponics," *Appl Clay Sci*, vol. 198, p. 105839, Nov. 2020.

[22] A. Nerlich and D. Dannehl, "Soilless Cultivation: Dynamically Changing Chemical Properties and Physical Conditions of Organic Substrates Influence the Plant Phenotype of Lettuce," *Front Plant Sci*, vol. 11, Jan. 2021.

[23] Z. Sun, M. Yi, X. Liu, S. Yixin, and J. Li, "Synergism Between Water Management and Phosphorus Supply Enhances the Nodulation and Root Growth and Development of Chinese Milk Vetch (Astragalus sinicus L.)," *Front Plant Sci*, vol. 12, Feb. 2022.

[24] C. P. Levine and N. S. Mattson, "Potassium-Deficient Nutrient Solution Affects the Yield, Morphology, and Tissue Mineral Elements for Hydroponic Baby Leaf Spinach (Spinacia oleracea L.)," *Horticulturae*, vol. 7, no. 8, p. 213, Jul. 2021.

[25] T. C. Silva *et al.*, "Macroelement omission in hydroponic systems changes plant growth and chemical composition of Melissa officinalis L. essential oil," *J Appl Res Med Aromat Plants*, vol. 24, p. 100297, Sep. 2021.

[26] O. Voutsinos-Frantzis *et al.*, "Exploring the Simultaneous Effect of Total Ion Concentration and K:Ca:Mg Ratio of the Nutrient Solution on the Growth and Nutritional Value of Hydroponically Grown Cichorium spinosum L.," *Agronomy*, vol. 12, no. 9, p. 2214, Sep. 2022.

[27] R. da Silva Cuba Carvalho, R. G. Bastos, and C. F. Souza, "Influence of the use of wastewater on nutrient absorption and production of lettuce grown in a hydroponic system," *Agric Water Manag*, vol. 203, pp. 311–321, Apr. 2018.

[28] S. G. Verdoliva, D. Gwyn-Jones, A. Detheridge, and P. Robson, "Controlled comparisons between soil and hydroponic systems reveal increased water use efficiency and higher lycopene and β-carotene contents in hydroponically grown tomatoes," *Sci Hortic*, vol. 279, p. 109896, Mar. 2021.

[29] G. P. Suárez-Cáceres, L. Pérez-Urrestarazu, M. Avilés, C. Borrero, J. R. Lobillo Eguíbar, and V. M. Fernández-Cabanás, "Susceptibility to water-borne plant diseases of hydroponic vs. aquaponics systems," *Aquaculture*, vol. 544, p. 737093, Nov. 2021.

[30] Y. S. Goh, Y. C. Hum, Y. L. Lee, K. W. Lai, W.-S. Yap, and Y. K. Tee, "A meta-analysis: Food production and vegetable crop yields of hydroponics," *Sci Hortic*, vol. 321, p. 112339, Nov. 2023.

[31] R. Combs-Giroir and A. R. Gschwend, "Physical and molecular responses to flooding in Brassicaceae," *Environ Exp Bot*, vol. 219, p. 105664, Mar. 2024.

[32] D. Parida, A. Behera, J. K. Naik, S. Pattanaik, and R. S. Nanda, "Real-time Environment Monitoring System using ESP8266 and ThingSpeak on Internet of Things Platform," in *2019 International Conference on Intelligent Computing and Control Systems (ICCS)*, IEEE, May 2019, pp. 225–229.

[33] S. A. Z. Murad, F. A. Bakar, A. Azizan, and M. A. M. Shukri, "Design of Internet of Things Based Air Pollution Monitoring System Using ThingSpeak and Blynk Application," *J Phys Conf Ser*, vol. 1962, no. 1, p. 012062, Jul. 2021.

[34] A. A. Mohamad, N. K. Jumaa, and S. H. Majeed, "Thingspeak Cloud Computing Platform Based ECG Diagnose System," *International Journal of Computing and Digital Systems*, vol. 8, no. 1, pp. 11–18, Jan. 2019.

[35] G. M., S. Raviteja, S. S., and R. Mahalakshmi, "Data Acquisition For Residential Energy Management Employing IoT Using ThingSpeak," in *2019 IEEE Region 10 Symposium (TENSYMP)*, pp. 272–276, Jun. 2019.