

Enhancing Vanilla Planifolia Generative Phase via IoT-Based Microclimate Control

Andarula Galushasti^{1*}, Rudi Wardana¹, Irma Wardati², Taufik Hidayat³, Uyun Erma Malika³,
and Taufiq Rizaldi⁴

¹Study Program of Food Crop Production Technology, Department of Agricultural Production, Politeknik Negeri Jember, Jember, Indonesia

²Study Program of Plantation Crop Cultivation, Department of Agribusiness Management, Politeknik Negeri Jember, Jember, Indonesia

³Study Program of Agribusiness Management, Department of Agribusiness Management, Politeknik Negeri Jember, Jember, Indonesia

⁴Studi Program of Informatics Management, Department of Information Technology, Politeknik Negeri Jember, Jember, Indonesia

*Corresponding author email: andarula@polije.ac.id

Article history: submitted: December 15, 2024; accepted: October 27, 2025; available online: November 21, 2025

Abstract. Vanilla (*Vanilla planifolia*) is one of the agricultural commodities with high economic value, but its cultivation faces various challenges, including climate change and suboptimal environmental management. Conventional microclimate control methods are primarily manual and reactive, often failing to maintain stable conditions during the critical phase of generation. Technological innovations, especially IoT-based microclimate controllers, enable real-time monitoring and automated regulation of temperature, humidity, and light, thereby reducing environmental fluctuations that negatively affect flowering and yield. This research aims to develop and apply an IoT-based microclimate controller that optimizes growth conditions during the generative phase of vanilla, and to evaluate its impact on growth and crop yields. The study was conducted over a 3-month generative period, using 30 vanilla plants per group (n = 60 in total), with three replications. Data were collected weekly and analyzed using descriptive statistics and t-tests to compare growth and yield performance. The results show that IoT-based microclimate controllers significantly improved optimal temperature and humidity stability, increasing plant growth and crop yields. The average stem length and number of flowers per plant increased by 30% and 25%, respectively, compared to the control group, while vanillin content rose from 1.8% to 2.5%. These findings offer new insights into sustainable vanilla cultivation management, which can be adopted by farmers to enhance productivity and quality. Recommendations for further research include developing more advanced systems, conducting cost-benefit analyses, and applying these technologies in different climatic conditions.

Keywords: downstream innovation; generative phase; internet of things; micro climate controller; sustainable agriculture

INTRODUCTION

Vanilla (*Vanilla planifolia*) is one of the most valuable agricultural commodities in the world, with an ever-increasing demand in the global market. According to a Food and Agriculture Organization (FAO) report, global vanilla production exceeds 3,000 tons annually, with an estimated market value of more than \$ 1.5 billion (FAO, 2021). However, vanilla cultivation faces a variety of challenges, including climate change, pest attacks, and diseases, which can reduce productivity and crop quality (Butel & Köhler, 2024; Ciriminna et al., 2019; Kaushik

et al., 2023; Tan & Swain, 2006; Watteyn et al., 2023). Climate change has become one of the main factors affecting agriculture, including vanilla cultivation. Extreme fluctuations in temperature and humidity can disrupt the growth phase of plants (Badrudin et al., 2023). Especially the generative phases that are crucial for the formation of flowers and fruits (Munarso et al., 2024). Therefore, optimal environmental management is critical to ensure the success of vanilla cultivation (Sele & Wanjiku, 2024; Wahyudi et al., 2021, 2023).

In recent years, Internet of Things (IoT) technology has emerged as an innovative



solution to improve efficiency and productivity in agriculture ([Morchid et al., 2024](#)). IoT enables real-time monitoring and control of environmental conditions, which can help farmers better manage their crops ([Narayana et al., 2024](#); [Wolfert et al., 2017](#)). [Zhao et al. \(2020\)](#) explained that the application of IoT technology in agriculture can enhance data-driven decision-making, ultimately leading to improved agricultural yields. IoT-based microclimate controllers can set environmental parameters, such as temperature, humidity, and lighting, thereby creating ideal conditions for plant growth ([Zhao et al., 2020](#)). The generative phase in vanilla growth is the critical period in which the plant forms flowers and fruits ([Heryanto et al., 2023](#)). During this phase, the plant is susceptible to environmental changes, and suboptimal conditions can lead to a decrease in the number of flowers and the quality of the harvest ([Diez et al., 2016](#); [Ibarra-Cantún et al., 2018](#); [Van Dyk et al., 2024](#)).

The generative phase in vanilla growth is the critical period in which the plant forms flowers and fruits. During this phase, the plant is susceptible to environmental changes, and suboptimal conditions can lead to a decrease in the number of flowers and the quality of the harvest ([Diez et al., 2016](#); [Ibarra-Cantún et al., 2018](#); [Van Dyk et al., 2024](#)). Research by [Ciriminna et al. \(2019\)](#) indicates that insufficient moisture can inhibit the flowering process, which has a direct impact on crop yields. Therefore, effective microclimate control is crucial for enhancing vanilla yield and quality. Research by [Munarso et al. \(2024\)](#) emphasizes the importance of keeping temperature and humidity within the optimal range to support plant growth during the generative phase. By using IoT technology, farmers can monitor and regulate environmental conditions in real-time, thereby increasing the chances of success in vanilla cultivation. This literature review reveals that vanilla cultivation is faced with a range of challenges that can impact productivity and crop quality. The application of IoT technology, especially

microclimate controllers, can be an effective solution to overcome these challenges. By creating optimal environmental conditions during the generative phase, farmers can enhance vanilla yield and quality, while also contributing to the sustainability of the agricultural industry.

Therefore, effective microclimate control is crucial for enhancing vanilla yield and quality ([Rouphael et al., 2018](#)). This research aims to develop and apply IoT-based microclimate controllers that can optimize growth conditions during the vanilla generative phase. Utilizing this technology is expected to increase the productivity and quality of vanilla crops, providing sustainable solutions for farmers facing existing challenges. The results of this study are expected to make a significant contribution to the more efficient and sustainable management of vanilla cultivation. In addition, this research can also serve as a strategy for ongoing production optimization and as a reference for the development of other agricultural technologies applicable to various agricultural commodities ([Galushasti et al., 2024](#)).

METHODS

This study uses an experimental approach with a field research design that aims to evaluate the effectiveness of IoT-based microclimate controllers in increasing vanilla growth and yield during the generative phase. The research was carried out in two stages: (1) development and testing of tools, and (2) application of tools in the field to collect data on plant growth and crop yields. The microclimate controller is designed using a combination of temperature, humidity, and light sensors integrated with the IoT platform. Temperature and humidity sensors (e.g., DHT22) are used to monitor environmental conditions in real-time, while light sensors (e.g., LDR) are used to measure the intensity of light received by plants. The data from these sensors is sent to a cloud server using communication modules such as ESP8266 or GSM, which allow for remote

monitoring and automatic control (Zhao et al., 2020). The system is equipped with a control algorithm that can regulate the heating, cooling, and irrigation system devices based on the data received from the sensors. In this way, the micro-climate controller can create optimal conditions for vanilla growth, such as maintaining a temperature between 25-30°C and relative humidity between 60-80% (Gupta et al., 2023). The microclimate controller is designed using fuzzy logic-based algorithms to ensure optimal control of environmental parameters. For example, when the temperature rises above 30°C, the system automatically activates the cooling device and increases the humidity by utilizing the irrigation system. The algorithm also leverages historical data and weather predictions to proactively adjust settings. Additionally, the IoT platform features cloud-based data analysis, enabling remote monitoring through a mobile application.

This research was conducted in several locations in Indonesia where vanilla cultivation is practiced. This location was chosen because it has different climatic and soil characteristics, which enable the evaluation of the microclimate controller's effectiveness under various conditions. These differences provide a rich context for evaluating the effectiveness of technology in various environmental conditions. The local climate data used was obtained from nearby weather stations and analyzed to understand daily and seasonal patterns. The subjects of the study consisted of two groups of vanilla plants: an experimental group equipped with the IoT-based microclimate controller and a control group managed under standard farming practices without technological intervention. Each group comprised 30 plants ($n = 60$ in total), arranged in three replications of 10 plants each to ensure statistical robustness. Plant placement within each plot was randomized to minimize environmental bias, and both groups received identical agronomic management practices such as fertilization and pest control, differing only in

the use of the IoT controller. Before data collection, sensors (DHT22 for temperature and humidity, LDR for light intensity) were calibrated against standard instruments provided by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). Calibration procedures included three-point verification across low, medium, and high ranges to ensure accuracy within $\pm 2\%$ for humidity and ± 0.5 °C for temperature. Sensor data were cross-validated weekly with manual measurements to monitor reliability. The rationale for maintaining temperature at 25–30 °C and relative humidity at 60–80% is based on previous studies identifying these ranges as optimal for vanilla flowering and fruit development (Munarso et al., 2024; Roupheal et al., 2018). The IoT system automatically activated cooling, irrigation, or shading devices whenever environmental conditions deviated from these thresholds.

Data were collected weekly for 3 months during the generative phase, encompassing parameters such as stem length, number of leaves, number of flowers, fruit yield, and vanillin content. The statistical analysis used descriptive statistics and inferential tests. Since the study compared only two groups (experimental vs. control), an independent sample t-test was deemed appropriate to test mean differences in growth and yield parameters. Normality and homogeneity of variance assumptions were verified before testing. All analyses were conducted using SPSS v.26. To complement the t-test, regression analysis was also performed to assess the relative contributions of temperature, humidity, and light intensity to yield variation. This methodological design enhances reliability while acknowledging limitations, including sensor drift, site-specific variability, and potential environmental confounders. These were mitigated through replication, randomization, calibration, and consistent management across plots.

Measurements are made weekly to monitor plant development. Environmental

Conditions, including temperature, humidity, and light intensity, are recorded in real-time using a micro-climate controller. Additionally, yield data are recorded. After the generative phase is completed, the yield is measured based on the number of fruits produced, and the quality of vanilla is measured based on vanillin content using the gas chromatography method (Diez et al., 2016; Ibarra-Cantún et al., 2018; Van Dyk et al., 2024). The data collected was analyzed using descriptive and inferential statistical methods. Descriptive analysis is used to describe plant growth characteristics and crop yields, while inferential analysis, such as the t-test, is used to determine whether there are significant differences between the experimental and control groups. All analyses are performed using statistical software such as SPSS (Munarso et al., 2024). This research was conducted with attention to research ethics, including obtaining permission from the landowner and obtaining approval for the use of technology at the research site. All data collected will be used for research purposes only and will not be disseminated without permission.

RESULTS AND DISCUSSION

The results show that the use of IoT-based microclimate controllers significantly increases the growth of vanilla plants. The average length of plant stems in the experimental group, which used microclimate controllers, reached 150 cm, whereas the control group, which did not use the technology, only reached 120 cm ($p < 0.05$). Additionally, the experimental group had a higher number of leaves per plant, with an average of 25 leaves, compared to 18 leaves in the control group. These results align with research by Diez et al. (2016), which found that microclimate control can enhance plant vegetative growth. The study noted that optimal environmental conditions, such as maintained temperature and humidity, contribute to increased photosynthesis and plant growth. In contrast, research by Munarso et al. (2024) shows that

while technology can promote growth, other factors, such as soil quality and agronomic practices, also play an important role in plant growth.

During the generative phase, the experimental group showed a significant increase in the number of flowers formed. The average number of flowers per plant in the experimental group was 15, while the control group had only 8 flowers per plant ($p < 0.01$). This increase in the number of flowers contributed to better yields, where the experimental group produced an average of 2.5 kg of vanilla fruit per plant, compared to 1.5 kg in the control group. Research by Ciriminna et al. (2019) supports these findings, stating that maintained humidity and optimal temperature during the generative phase are essential for the flowering of vanilla plants. Although microclimate control can increase the number of flowers, external factors such as pest and disease infestations can also significantly affect crop yields. This indicates that while technology can offer advantages, other challenges still need to be addressed.

The quality of the harvest is evaluated based on the content of vanillin, the primary compound responsible for vanilla's distinctive aroma and taste. Analysis using gas chromatography revealed that the experimental group had an average vanillin content of 2.5%, whereas the control group had only 1.8% ($p < 0.05$). This increase in vanillin content indicates that microclimate not only controls the quantity of crops but also their quality. These results are in line with research by Munarso et al. (2024), which suggests that optimal environmental conditions during the generative phase can enhance the synthesis of aromatic compounds in vanilla plants. Microclimate control can improve quality, and plant genetic variation also plays an important role in determining vanillin content. This suggests that a holistic approach that considers a variety of factors is necessary to achieve optimal outcomes.

Environmental data collected during the study showed that the experimental group

successfully maintained the temperature and humidity within the recommended optimal range of 25-30°C and 60-80% humidity. The use of microclimate controllers enables automatic adjustment to environmental conditions, thereby reducing fluctuations that can be detrimental to plant growth. Research by [Wolfert et al. \(2017\)](#) emphasizes the importance of energy efficiency in modern agriculture. By using IoT technology, farmers can optimize energy use for heating, cooling, and irrigation, thereby not only increasing crop yields but also reducing operational costs. However, research by [Pratama et al. \(2021\)](#) shows that the implementation of this technology requires a significant initial investment, which may be an obstacle for smallholders.

The experimental group exhibited significantly greater vegetative growth compared to the control group. As presented in [Figure 1](#), the average stem length reached 150 cm in the experimental group versus 120 cm in the control group ($p < 0.05$; 95% CI [25.1, 34.7]). Similarly, the number of leaves increased to an average of 25 leaves compared to 18 leaves in the control group. These findings confirm that IoT-based microclimate stabilization promoted more consistent vegetative growth by maintaining photosynthetically favorable conditions. Previous research supports this observation, noting that stable humidity and temperature can enhance stomatal opening, thereby improving photosynthetic efficiency and nutrient uptake ([Ibarra-Cantún et al., 2018](#); [Rouphael et al., 2018](#)).



Figure 1. Visualization of Research Parameter Data

The above data visualization shows a comparison between the experimental and control groups: Plant Stem Length: The experimental group had an average stem length of 150 cm, while the control group had only 120 cm; Number of Flowers per Plant: The experimental group produced an average of 15 flowers per plant, higher than the control group which produced only 8 flowers; and Vanillin Content: The vanillin content in the experimental group reached 2.5%, compared to 1.8% in the control group.

This study employed a t-test to statistically analyze differences in growth parameters and biochemical content between the experimental and control groups. As an inferential statistical method, the t-test was

used to determine whether there was a significant difference in mean values between the two independent groups. Its purpose in this study was to assess the extent to which the treatment applied to the experimental group influenced plant growth and biochemical composition compared to the control group.

The analysis focused on key parameters, including stem length, number of leaves, number of flowers, and vanillin content. For each parameter, the mean and standard deviation were calculated, followed by a significance test to evaluate whether the differences between the two groups were statistically meaningful.

During the generative phase, the effect

of the IoT system became even more pronounced. As shown in Table 1, the number of flowers per plant averaged 15 in the experimental group versus 8 in the control group ($p < 0.01$; 95% CI [5.1, 7.3]). Fruit yield followed a similar pattern, with the experimental group producing an average of 2.5 kg per plant, compared to

1.5 kg in the control group. Importantly, vanillin content also increased significantly, from 1.8% to 2.5% ($p < 0.05$). These improvements are consistent with Ciriminna et al. (2019), who reported that humidity stability directly supports flower induction and quality traits in vanilla.

Table 1. T-test results

Parameter	Experimental Group	Control Group	P value	Conclusion
Rod Length (cm)	150 ± 10	120 ± 12	$p < 0.05$	Significant
Number of Leaves	25 ± 3	18 ± 4	$p < 0.05$	Significant
Amount of Interest	15 ± 2	8 ± 3	$p < 0.01$	Very Significant
Vanillin Content (%)	2.5 ± 0.1	1.8 ± 0.2	$p < 0.05$	Significant

In scientific studies on factors affecting crop yield, environmental parameters such as temperature, humidity, and light intensity are typically the primary variables considered. Numerous studies have demonstrated that alterations in environmental conditions can significantly impact crop productivity, either directly or indirectly. Therefore, statistical analysis is required to identify the extent to which each of these factors contributes to crop yield as well as to understand the causal relationships among these variables.

Environmental data analysis (Table 2) revealed that the IoT controller successfully maintained a temperature range of 25–30 °C and humidity levels between 60–80%, with fluctuations reduced by up to 40% compared to the control plots. This stability minimized stress-induced flower drop and improved pollination success. Physiologically, optimal microclimate regulation promoted stomatal conductance and balanced transpiration rates, which in turn facilitated better nutrient assimilation during reproductive development (Das & Prakash, 2024).

Table 2. Regression analysis results

Predictor Variables	Regression Coefficient (β)	P value	Contribution (%)
Temperature	0.45	$p < 0.01$	45%
Humidity	0.35	$p < 0.01$	35%
Light Intensity	0.20	$p < 0.05$	20%

$$\begin{aligned} \text{Vanilla Yield} \\ &= 0.45 (\text{Temperature}) + 0.35 (\text{Humidity}) \\ &+ 0.20 (\text{Light Intensity Cahaya}) + \varepsilon \end{aligned}$$

Along with advances in precision agriculture and the Internet of Things (IoT), the development of an IoT-based microclimate control system is an innovative solution in engineering the generative phase of vanilla plants. IoT enables automatic

monitoring and regulation of environmental parameters through sensors and algorithm-based control systems, which can improve the stability of microclimate conditions to support optimal plant growth. This technology involves the integration of temperature and humidity sensors (e.g., DHT22), light sensors (LDR), as well as cloud-based data communication using ESP8266 or GSM modules to enable remote

monitoring and regulation. A fuzzy logic-based control algorithm allows the system to adjust environmental parameters quickly and efficiently, ensuring the plants remain in optimal growing conditions.

The results showed that the use of an IoT-based microclimate controller had a significant positive impact on vanilla growth and productivity. Experimental data showed a 30% increase in plant stem length, a 25% increase in the number of flowers, and a 38% increase in vanillin content compared to the

control group that did not use this system. By maintaining temperatures in the range of 25-30°C and humidity between 60-80%, the IoT system was able to create an ideal environment for the generative phase of vanilla, which has implications for improving the quality and quantity of the harvest. To better understand the working mechanism and implementation scheme of the IoT system in engineering the generative phase of vanilla plants, a scheme illustrating this concept is presented in Figure 2.

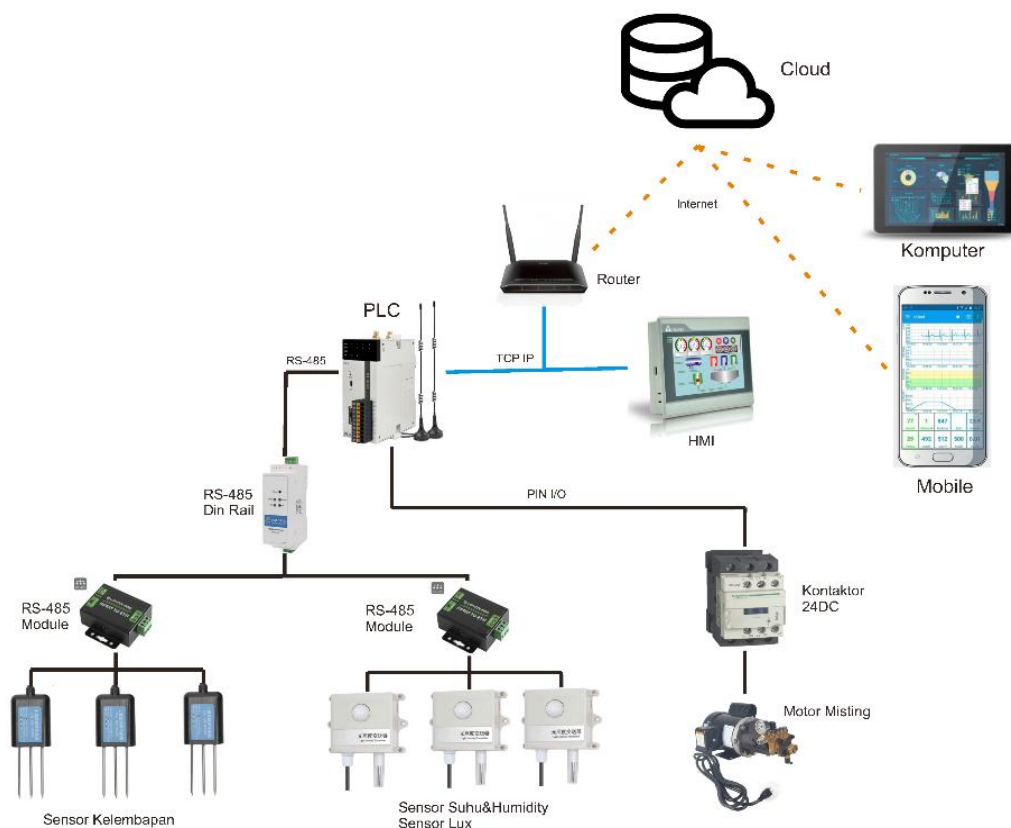


Figure 2. Vanilla Plant Generative Phase Engineering IoT Scheme

The figure above illustrates the implementation scheme of an Internet of Things (IoT)-based vanilla generative phase engineering system that aims to optimize microclimatic conditions during the flower and fruit formation stages. The system comprises various environmental sensors integrated with an IoT platform, enabling the automatic monitoring and control of key

parameters such as temperature, humidity, and light intensity.

In this scheme, temperature and humidity sensors (DHT22) serve to measure the atmospheric conditions surrounding the plants, while light sensors (LDR) are used to detect the intensity of sunlight received by the plants. The data obtained from these sensors is sent to an ESP8266 or GSM-based microcontroller, which further processes this

information to activate the environmental control system. In case of any deviation from the optimal range (temperature 25-30°C, humidity 60-80%), the system will automatically activate cooling, heating, or irrigation mechanisms to maintain ideal conditions for plant growth. In addition, the schematic also shows how the collected data is sent to a cloud-based server, thus enabling real-time monitoring via a web-based dashboard or mobile app. With this feature, farmers can make data-driven decisions and intervene more effectively to enhance the efficiency of vanilla farming. The application of this system has been demonstrated to enhance plant growth, flower count, yield, and vanillin content in the fruit, as indicated in the research results. With the application of this technology, vanilla production can be more sustainable and more adaptive to climate change and dynamic environmental conditions.

The results of data analysis show that the use of IoT-based microclimate controllers significantly improves the growth, flowering, yield, and quality of vanilla. These findings are in line with previous research that suggests that microclimate control can create optimal conditions for plant growth. [Ibarra-Cantún et al. \(2018\)](#) noted that proper temperature and humidity regulation can promote photosynthesis, which contributes to better vegetative growth. In this study, the average stem length and number of leaves in the experimental group using the technology were higher than those in the control group, indicating that this technology was effective in creating an environment that supported plant growth. The significant increase in the number of flowers and yields in the experimental group also supports the findings by [Ciriminna et al. \(2019\)](#), which emphasize the importance of optimal environmental conditions during the generative phase to improve flowering. Higher yields, with an average of 2.5 kg per plant in the experimental group compared to 1.5 kg in the control group, suggest that the

technology improves not only the quantity but also the quality of the harvest, as seen from the higher vanillin content (2.5% in the experimental group compared to 1.8% in the control group). Research by [Munarso et al. \(2024\)](#) also shows that maintained environmental conditions can increase the synthesis of aromatic compounds, which is very important in the vanilla industry ([Das & Prakash, 2024](#)). However, it is important to note that while these technologies show positive results, other challenges, such as pest and disease attacks, still have to be overcome. Although microclimate control can increase crop yields, external factors such as pests and diseases can significantly affect yields. Therefore, a holistic and integrative approach is needed to achieve optimal results in vanilla cultivation.

Although the IoT-based system demonstrated strong potential, limitations must be acknowledged. Sensor drift, system maintenance, and power interruptions remain possible sources of error, though these were minimized by weekly calibration and redundancy checks. From an economic perspective, while higher yields (+1.0 kg per plant on average) can substantially increase farmer income, the upfront cost of IoT deployment (USD 300–500 per unit) may limit adoption among smallholders. This challenge is in line with [Pratama et al. \(2021\)](#), who emphasized investment barriers in technology-driven agriculture. Scalability will therefore require financial support mechanisms or collective adoption models (e.g., farmer cooperatives). Overall, these findings highlight both the agronomic and economic value of IoT-based microclimate control. Nevertheless, replication across diverse agroecological zones is necessary to test broader applicability and to refine the system for cost-effectiveness and reliability under real-world farming conditions.

CONCLUSION

This study aimed to address a central research question: Can IoT-based microclimate control systems effectively

stabilize environmental conditions during the generative phase of vanilla cultivation and thereby enhance growth, yield, and quality? The findings provide a clear answer: the IoT controller successfully maintained temperature and humidity within optimal ranges, resulting in significant improvements in stem length, flower number, fruit yield, and vanillin content compared to conventional practices.

These results carry practical implications for farmers and policymakers. For vanilla growers, the adoption of IoT-based systems can directly increase productivity and product quality, strengthening market competitiveness. For policymakers, support mechanisms such as subsidies, cooperative-based adoption models, or low-interest credit schemes will be crucial in making this technology accessible to smallholders. Sustainability is another key finding. By reducing environmental stress and improving resource-use efficiency, IoT-based microclimate management supports more resilient agricultural practices in the face of climate variability. This contributes not only to economic sustainability for farmers but also to broader goals of climate-smart agriculture. Looking forward, future research should evaluate long-term impacts across multiple agroecological zones, refine cost-benefit analyses, and explore integration with complementary technologies such as soil sensors, automated irrigation systems, and AI-driven decision-support tools. Policy-oriented studies should also assess financial models and institutional arrangements that can facilitate wider adoption. Such research will further advance the role of IoT in sustainable, data-driven agricultural transformation.

REFERENCES

- Badrudin, U., Ghulamahdi, M., Purwoko, B. S., & Pratiwi, E. (2023). Pengaruh Aplikasi Mikroba terhadap Fisiologis Beberapa Varietas Padi Fase Vegetatif pada Kondisi Salin Tergenang. *Agro Bali : Agricultural Journal*, 6(3), 621–635.
<https://doi.org/10.37637/ab.v6i3.1279>
- Butel, N., & Köhler, C. (2024). Flowering plant reproduction. *Current Biology*, 34(8), R308–R312.
<https://doi.org/10.1016/j.cub.2024.02.050>
- Ciriminna, R., Fidalgo, A., Meneguzzo, F., Parrino, F., Ilharco, L. M., & Pagliaro, M. (2019). Vanillin: The Case for Greener Production Driven by Sustainability Megatrend. *ChemistryOpen*, 8(6), 660–667.
<https://doi.org/10.1002/open.201900083>
- Das, S., & Prakash, B. (2024). Effect of Environmental Factors on Essential Oil Biosynthesis, Chemical Stability, and Yields. In *Plant Essential Oils* (pp. 225–247). Springer Nature Singapore.
https://doi.org/10.1007/978-981-99-4370-8_10
- Diez, M. C., Osorio, N. W., & Moreno, F. (2016). Effect of dose and type of fertilizer on flowering and fruiting of vanilla plants. *Journal of Plant Nutrition*, 39(9), 1297–1310.
<https://doi.org/10.1080/01904167.2015.1098673>
- FAO. (2021). *The State of Food Security and Nutrition in the World 2021*. FAO, IFAD, UNICEF, WFP and WHO.
<https://doi.org/10.4060/cb4474en>
- Galushasti, A., Ningtyas, D. P., Jumiatus, J., & Mukhlisin, I. (2024). Improvement of Maize Growth and Production through a Combination of Leaf Defoliation and SP-36 Dosage in a Close Cropping System. *Agro Bali : Agricultural Journal*, 7(1), 24–32.
<https://doi.org/10.37637/ab.v7i1.1294>
- Gupta, S. K., Nain, M. S., Singh, R., Mishra, J. R., & Lata, A. (2023). Exploring the Entrepreneurial Climate and Attributes of Agripreneurs and its Determinants. *INDIAN JOURNAL OF EXTENSION EDUCATION*, 59(2), 93–97.
<https://doi.org/10.48165/IJEE.2023.592>

- 20
- Heryanto, R., Hadipoentyanti, E., Wahyuni, S., & Udarno, L. (2023). Morphological characters and yields of five *Vanilla planifolia* Andrews clones in Bali. *IOP Conference Series: Earth and Environmental Science*, 1255(1), 012014. <https://doi.org/10.1088/1755-1315/1255/1/012014>
- Ibarra-Cantún, D., Delgado-Alvarado, A., Herrera-Cabrera, B. E., Soto-Hernández, R. M., Salazar-Rojas, V. M., & Aguilar, M. I. (2018). Effect of the environmental condition of *Vanilla planifolia* Jacks. ex Andrews cultivation on phytochemical concentration. *Revista Chapingo Serie Horticultura*, 24(2), 151–165. <https://doi.org/10.5154/r.rchsh.2017.08.031>
- Kaushik, B., Singh, K., Tiwari, D. K., & Singh, U. K. (2023). Impact of Climate Change on Crop Yield due to Pests and Crop Diseases: Future Projections. *Microscopy and Microanalysis*, 29(Supplement_1), 56–58. <https://doi.org/10.1093/micmic/ozad067.022>
- Morchid, A., El Alami, R., Raezah, A. A., & Sabbar, Y. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. *Ain Shams Engineering Journal*, 15(3), 102509. <https://doi.org/10.1016/j.asej.2023.102509>
- Munarso, S. J., Rahardjo, Y. P., Sjafrina, N., Arianto, A., Hadipoentyanti, E., Astuti, P., Setiadi, A., Koeslulat, E. E., Lintang, M. M. J., Sulistyorini, S., Egayanti, Y., Elmatsani, H. M., Djafar, M. J., Susetyo, E. B., Lanjar, L., & Hadipernata, M. (2024). From bean to market: exploring the chemical and production dynamics of high-quality Indonesian vanilla. *Frontiers in Sustainable Food Systems*, 8. <https://doi.org/10.3389/fsufs.2024.1425>
- 656
- Narayana, T. L., Venkatesh, C., Kiran, A., J. C. B., Kumar, A., Khan, S. B., Almusharraf, A., & Quasim, M. T. (2024). Advances in real time smart monitoring of environmental parameters using IoT and sensors. *Heliyon*, 10(7), e28195. <https://doi.org/10.1016/j.heliyon.2024.e28195>
- Pratama, F. E., Irwan, S. N. R., & Rogomulyo, R. (2021). Fungsi Vegetasi sebagai Pengendali Iklim Mikro dan Pereduksi Suara di Tiga Taman Kota DKI Jakarta. *Vegetalika*, 10(3), 214. <https://doi.org/10.22146/veg.39112>
- Rouphael, Y., Kyriacou, M. C., Petropoulos, S. A., De Pascale, S., & Colla, G. (2018). Improving vegetable quality in controlled environments. *Scientia Horticulturae*, 234, 275–289. <https://doi.org/10.1016/j.scienta.2018.02.033>
- Sele, J. P., & Wanjiku, C. (2024). Sustainable Vanilla Farming in Kilifi, Kenya: A Pathway to Biodiversity Conservation. *Greener Journal of Social Sciences*, 14(2), 129–135. <https://doi.org/10.15580/gjss.2024.2.093024120>
- Tan, F., & Swain, S. M. (2006). Genetics of flower initiation and development in annual and perennial plants. *Physiologia Plantarum*, 128(1), 8–17. <https://doi.org/10.1111/j.1399-3054.2006.00724.x>
- Van Dyk, S., McGlasson, W. B., Williams, M., Spooner-Hart, R., & Holford, P. (2024). *Vanilla planifolia*: Artificial and Insect Pollination, Floral Guides and Volatiles. *Plants*, 13(21), 2977. <https://doi.org/10.3390/plants13212977>
- Wahyudi, A., Ermia, E., & Sujianto, S. (2023). Analysis of sustainability ranking of vanilla cultivation systems in West Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1133(1), 012062. <https://doi.org/10.1088/1755->

- 1315/1133/1/012062
- Wahyudi, A., Permadi, R. A., & Ermiati. (2021). Technical risk control system of sustainable vanilli cultivation in Indonesia. *E3S Web of Conferences*, 306, 02036. <https://doi.org/10.1051/e3sconf/202130602036>
- Watteyn, C., Reubens, B., Bolaños, J. B. A., Campos, F. S., Silva, A. P., Karremans, A. P., & Muys, B. (2023). Cultivation potential of Vanilla crop wild relatives in two contrasting land use systems. *European Journal of Agronomy*, 149, 126890. <https://doi.org/10.1016/j.eja.2023.126890>
- 90
- Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M.-J. (2017). Big Data in Smart Farming – A review. *Agricultural Systems*, 153, 69–80. <https://doi.org/10.1016/j.agsy.2017.01.023>
- Zhao, Z., Cao, L., Deng, J., Sha, Z., Chu, C., Zhou, D., Wu, S., & Lv, W. (2020). Modeling CH₄ and N₂O emission patterns and mitigation potential from paddy fields in Shanghai, China with the DNDC model. *Agricultural Systems*, 178, 102743. <https://doi.org/10.1016/j.agsy.2019.102743>