

Integrating Experimental Evaluation and Bibliometric Analysis of Photosynthetic Bacteria and Jakaba as Bioactivators for Sustainable Organic Agriculture

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Received: May 04, 2025

Revised: June 20, 2025

Accepted: July 25, 2025

Published: July 31, 2025

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DOI: [10.29303/jppipa.v11i7.11789](https://doi.org/10.29303/jppipa.v11i7.11789)

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Abstract: The excessive use of synthetic chemical inputs in agriculture has led to soil degradation, highlighting the need for environmentally friendly bioactivator alternatives. This study aims to integrate bibliometric analysis and experimental evaluation of Photosynthetic Bacteria (PSB) and Jakaba (*Corallomycetella repens*) as bioactivators in organic farming systems. Bibliometric analysis was conducted using Scopus publications from 2015–2025 and visualized with VOSviewer to map research trends, dominant keywords, and the publication status of PSB and Jakaba. A field experiment was then carried out in Kaluku Tinggi Village, Sigi District, using hybrid corn (*Bisi-18*) with four treatments: control, PSB, Jakaba, and a combination of PSB+Jakaba. Data were analyzed using ANOVA and Tukey HSD test, supported by Response Surface Methodology (RSM) for treatment effectiveness evaluation. Results showed that the PSB+Jakaba combination increased plant height (15.3%), fresh weight (20.9%), dry weight (25.1%), soil pH (13.5%), organic C content (41.2%), cation exchange capacity (27.6%), microbial population (24%), and dehydrogenase activity (36.3%) compared to the control. Active compounds such as IAA and siderophores from PSB, along with lignocellulolytic enzymes from Jakaba, played key roles in improving soil quality. This study bridges the scientific knowledge gap and reinforces the potential of local bioactivator formulations for sustainable organic farming on marginal land.

Keywords: Biactivator; Bibliometrics; Jakaba; Organic farming; Photosynthetic bacteria

Introduction

Organic agriculture is increasingly regarded as a viable alternative to conventional farming systems in response to the ongoing ecological crisis caused by excessive reliance on synthetic chemical inputs (Gamage et al., 2023; Bala et al., 2022; Thakur et al., 2022). The intensive use of inorganic fertilizers and chemical pesticides has been proven to generate long-term negative effects on soil quality, biodiversity, human health, and environmental pollution (Fudjoe et al., 2025;

Patthawaro et al., 2020). Recent data from the Food and Agriculture Organization (FAO, 2024) reported that global consumption of inorganic fertilizers surpassed 185 million tons in 2022, while the average pesticide use in Indonesia reached 6.5 kg per hectare per year making it one of the highest in Southeast Asia. This dependency not only accelerates the degradation of soil fertility due to heavy metal accumulation and chemical residues but also reduces the population of beneficial soil microbes essential for natural nutrient cycling (Chen et al., 2025; Khan et al., 2022; Abebe et al., 2022). This phenomenon

How to Cite:

Nanda, Lubis, R. A., Mukhlis, Nasution, F. E., & Sipahutar, L. W. Integrating Experimental Evaluation and Bibliometric Analysis of Photosynthetic Bacteria and Jakaba as Bioactivators for Sustainable Organic Agriculture. *Jurnal Penelitian Pendidikan IPA*, 11(7), 142-151. <https://doi.org/10.29303/jppipa.v11i7.11789>

underscores the urgent need to transition toward ecologically and microbiologically based farming systems. As emphasized by Altieri et al. (2020), the diversity of soil microorganisms forms the foundation for long-term agroecosystem resilience. Therefore, innovative approaches are needed to utilize local biological agents, such as photosynthetic bacteria and endophytic fungi, as bioactivators capable of restoring soil functions in a sustainable manner.

One of the most important groups of soil microorganisms supporting organic farming systems is photosynthetic bacteria (PSB), particularly from the genus *Rhodospseudomonas*, such as *R. palustris*. These microbes are known for their multifunctional capabilities, including free nitrogen fixation through the nitrogenase enzyme, phosphate solubilization with the aid of phosphatase and organic acids, and the production of various plant growth regulators such as indole-3-acetic acid (IAA), cytokinins, gibberellins (GA₃), and 5-aminolevulinic acid (ALA) (Abdelaal et al., 2021; Suzuki et al., 2025; Wang et al., 2021). In addition, PSB also produce other beneficial compounds such as hydroxamate-type siderophores that enhance iron availability, antioxidants like spirilloxanthin and bacteriochlorophyll a, and polyhydroxybutyrate (PHB) as an energy reserve (Cao et al., 2020; Patthawaro et al., 2020; Brown et al., 2022). Enzymes such as ACC-deaminase and peroxidase produced by these bacteria also contribute to the detoxification of heavy metals and pesticides, while simultaneously enhancing the activity of indigenous rhizospheric microbes, thereby improving overall soil health and structure (Hsu et al., 2021; Nguyen Quoc et al., 2023). As explained by (Kavamura & Esposito, 2010), plant growth promoting bacteria (PGPB) such as PSB play a significant role in soil bioremediation and improving nutrient availability, which is essential in organic farming ecosystems that do not rely on synthetic inputs.

The practical application of photosynthetic bacteria has been proven effective when carried out during the early stages of plant growth, such as through seed priming, root dipping during transplantation, or foliar spraying during the early vegetative phase. Regular application every 2–3 weeks can also enhance root colonization and improve fertilizer use efficiency (Sabki et al., 2021). Historically, this group of bacteria was first studied by Johannes Molisch in 1907, later classified scientifically by Cornelis B. van Niel in 1944, and began to be widely applied in agriculture in Japan during the 1980s. Global research trends on PSB have shown a sharp increase, particularly after 2015, in line with growing awareness of the need for sustainable and low-emission farming systems (Li et al., 2022; Sundar et al., 2024). Recent bibliometric data also confirm the increasing scientific interest in PSB as a promising

bioactivator to enhance nutrient use efficiency and support low-carbon agroecosystems.

Jakaba, an acronym for *Jamur Keberuntungan Abadi* (Eternal Luck Fungus), is a locally developed fermentation product that was first discovered unintentionally by Aba Junaidi Sahidj while formulating liquid organic fertilizer (LOF) from natural ingredients. The fermentation process, which involves rice rinsing water (*leri*), rice bran, fermented shrimp paste (*terasi*), mung beans, bamboo roots, and rainwater, spontaneously produces fungal colonies on the surface of the solution, which are then utilized as bioactivators (Puspitasari et al., 2022; Wei et al., 2023). The dominant microorganisms found in Jakaba have been identified as endophytic and saprophytic fungi, with *Corallomycetella*, particularly *Corallomycetella repens*, as the main candidate species known for its high lignocellulolytic capability (Mutaqqim, 2025). As a locally sourced fungal-based bioactivator, Jakaba reflects an ecological approach rooted in indigenous knowledge, with great potential for development into a modern biological innovation especially in tropical regions with high microbial diversity (Altieri & Toledo, 2011).

Biochemically, Jakaba contains key enzymes such as cellulase, hemicellulase, ligninase, and pectinase, which play essential roles in accelerating the decomposition of complex organic materials such as straw, husks, and other agricultural residues. In addition, secondary metabolites such as natural phytohormones particularly auxins, gibberellins, and abscisic acid in low concentrations—and volatile antibacterial compounds contribute to the microbial competitiveness of Jakaba in the soil environment (Fadilah et al., 2024; Irwandhi et al., 2025). Through these enzymatic activities, Jakaba can accelerate the humification process and stimulate root development, making it a multifunctional biological agent that supports the sustainability of organic agriculture. Several studies have shown that the application of lignocellulolytic fungus-based decomposer agents such as *Corallomycetella* can significantly enhance the availability of macronutrients through the biotransformation of plant residues.

The application of Jakaba is considered most effective during the early stages of soil preparation and composting of organic materials, and it can also be sprayed onto the soil surface prior to planting or during the vegetative growth phase of. However, despite its great potential, Jakaba has not been widely explored in reputable scientific publications, particularly in terms of microbial characterization, fermentation stability, product formulation, and its synergy with other biological agents such as photosynthetic bacteria (Puspitasari et al., 2022). This gap in the literature presents a wide opportunity for further research,

especially regarding the integration of local fungi with modern biotechnological approaches. On the other hand, research on photosynthetic bacteria (PSB) has advanced rapidly over the past two decades and has been widely applied as a bioactivator in various global agricultural ecosystems. Nevertheless, there is still no comprehensive study that specifically evaluates the synergistic interaction between PSB and *Jakaba* within a single, integrated research framework. The absence of such integrative studies highlights a significant scientific gap that must be addressed through locally based experimental approaches.

Bibliometric analysis has become a strategic tool in the development of sustainable agricultural technologies, allowing researchers to map research trends, identify key collaborators, and determine the geographical distribution of specific scientific topics. Tools such as VOSviewer can be used to visualize the relationship patterns among authors, institutions, and dominant keywords found in international literature. This method is essential for identifying research gaps, collaboration opportunities, and areas of innovation that remain underexplored (Donthu et al., 2021; Mukherjee et al., 2022). In the context of organic agriculture, bibliometric analysis can be applied to assess the extent to which microorganisms such as photosynthetic bacteria (PSB) have become central topics in scientific publications and agronomic practices, as well as to observe global scientific dynamics driving research in this field (Rejeb et al., 2022).

This study represents the first to simultaneously integrate global bibliometric analysis and field-based experimental evaluation to examine the synergistic potential of Photosynthetic Bacteria (PSB) and *Jakaba* (*Corallomycetella repens*) as bioactivators in tropical organic farming systems. No previous studies have comprehensively combined global scientific mapping with biological performance testing of these two microorganisms within a single integrated research framework. The primary objective of this study is to evaluate the effectiveness of the PSB and *Jakaba* combination in improving soil quality, accelerating the decomposition of organic matter, and supporting the organic cultivation of maize. This innovation not only highlights the individual scientific contributions of PSB and *Jakaba* but also explores their potential synergistic effects in enhancing soil conditions ecologically. The findings of this study are expected to provide both scientific and practical foundations for developing more efficient, cost-effective, and sustainable local bioactivator formulations to support organic farming systems on marginal land.

Method

This study employed a mixed method sequential exploratory approach by integrating bibliometric analysis and experimental evaluation to investigate the synergistic potential of Photosynthetic Bacteria (PSB) and *Jakaba* (*Corallomycetella repens*) as bioactivators in organic farming systems. The research was conducted from February to July 2024 at an organic farming demonstration plot in Kaluku Tinggu Village, Dolo Barat Subdistrict, Sigi Regency, Central Sulawesi, Indonesia. The first phase involved bibliometric analysis to identify research trends, scientific collaboration networks, and global topic focuses related to PSB and *Jakaba*. Publication data were obtained from the Scopus database for the 2015-2025 period using the keywords "Photosynthetic bacteria," "organic farming," and "Jakaba" or "Corallomycetella repens." The extracted metadata were processed using the Publish or Perish application and analyzed with VOSviewer software, which included co-occurrence keyword analysis and density visualization mapping.

The second phase consisted of a field-based experimental evaluation using a Randomized Complete Block Design (RCBD) with four treatments and three replications: P0 (control, no bioactivator), P1 (PSB 50 ml/L), P2 (*Jakaba* 50 ml/L), and P3 (PSB 50 ml/L + *Jakaba* 50 ml/L combination). The test plant used was hybrid maize (*Zea mays* L., variety Bisi-18), cultivated organically without chemical fertilizer, using local soil that had been fallowed. Observed parameters included agronomic variables (plant height, leaf number, fresh weight, dry weight), soil physicochemical properties (pH, organic carbon content, and cation exchange capacity), and soil microbiological characteristics (total microbial population in CFU/g and dehydrogenase enzyme activity as a microbial respiration indicator).

Observation data were analyzed using analysis of variance (ANOVA) with the help of SPSS software, followed by Tukey HSD test at a 5% significance level. To evaluate the effectiveness of the treatment combinations and determine the optimal dose, Response Surface Methodology (RSM) was applied using Design Expert software. The experimental findings were then integrated with the bibliometric results to strengthen scientific arguments and develop recommendations for locally based bioactivator formulations in support of efficient and sustainable organic farming systems.

Result and Discussion

Bibliometric Analysis

The bibliometric analysis in this study was conducted to evaluate global research trends, keyword co-occurrence networks, and the distribution of country

Figure 1 illustrates the keyword co-occurrence network most frequently found in the literature on PSB and organic agriculture. Keywords such as *photosynthetic bacteria*, *biofertilizer*, *sustainable agriculture*, and *soil fertility* form a major interconnected cluster. This indicates a consistent global research focus on optimizing microorganisms for sustainable agriculture. Notably, the terms “Jakaba” and *Corallomycetella repens* were not identified in the network, reaffirming the scientific novelty of this study.

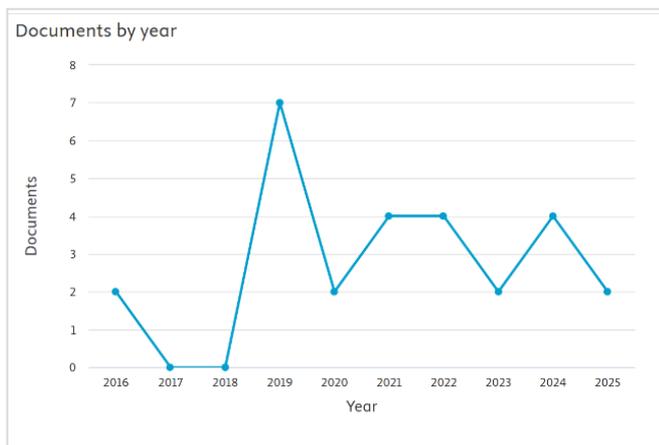


Figure 2. Annual publication distribution diagram (2015-2025)

The distribution of publication numbers shows a positive growth trend from year to year. A significant increase has been observed since 2019, corresponding with a global surge of interest in environmentally friendly agriculture and bio-based solutions. As of May 2025, only 27 publications have been recorded, indicating that the trend for the year is still ongoing. This

graph reinforces the urgency and global relevance of PSB as a research topic at the international level.

Experimental Evaluation of PSB and Jakaba as Bioactivators in Organic Agriculture

This study aimed to assess the effectiveness of Photosynthetic Bacteria (PSB) and Jakaba (*Corallomycetella repens*) as bioactivators in supporting the growth of hybrid maize (*Zea mays* L.) under organic cultivation. The results demonstrated that treatments involving PSB, Jakaba, and their combination had a significant impact on various agronomic parameters, as well as on soil physicochemical and microbiological properties, compared to the control. Notable improvements were observed in plant height, number of leaves, fresh and dry biomass, and the concentrations of key macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). Additionally, there was an increase in the population of beneficial soil microbes, including phosphate-solubilizing and nitrogen-fixing bacteria.

These findings are consistent with the results of Vishnupradeep et al. (2022), who reported that PSB application in organic farming systems enhanced soil quality and maize yield. Similarly, Bay et al. (2021) observed that microbial bioactivators accelerated soil microbiological activity and improved nutrient uptake efficiency. Further noted that PSB application in organic cultivation not only promoted plant growth but also significantly improved soil structure and water retention.

The following section presents a more detailed and accessible overview of the experimental results, highlighting the increases observed in each measured parameter.

Table 2. Agronomic Parameters of Hybrid Corn Plants, Bisi-18 Variety

Treatment	Plant Height (cm)	Number of leaves (blades)	Fresh Weight (g)	Dry Weight (g)
P0 (Control)	157 ± 4.5a	10.3 ± 0.4a	416 ± 18a	115 ± 6a
P1 (PSB)	174 ± 5.1b	12.8 ± 0.5b	502 ± 20b	139 ± 7b
P2 (Jakaba)	179 ± 4.7b	13.1 ± 0.6b	518 ± 21b	143 ± 6b
P3 (PSB + Jakaba)	195 ± 5.3c	14.6 ± 0.7c	563 ± 22c	159 ± 8c

Note: Values followed by different letters indicate significant differences (Tukey HSD test, p < 0.05).

All agronomic parameters of hybrid maize treated with Photosynthetic Bacteria (PSB) and Jakaba showed significant improvements, as presented in Table 2. The combined treatment of PSB and Jakaba (P3) yielded the best results, with an average plant height of 195 cm an increase of 38 cm compared to the control, which reached only 157 cm. This indicates that the combination of the two bioactivators effectively stimulated vegetative growth. This finding is supported by Bala et al., (2022), who stated that the synergy between photosynthetic microbes and endophytic fungi enhances nutrient and

phytohormone availability, contributing to internode elongation and stem growth.

An increase was also observed in the number of leaves, with an average of 14.6 leaves in the P3 treatment, which is 4.3 more than the control (10.3 leaves). A greater number of leaves supports higher photosynthetic capacity, thereby accelerating growth processes and biomass accumulation. Enhanced photosynthetic efficiency directly contributes to greater plant productivity.

In terms of fresh biomass, the P3 treatment produced 563 g, which is 147 g higher than the control (416 g). This increase in fresh biomass reflects a positive physiological response of the plant to microbial bioactivation, as also reported by Hsu et al., (2021) and Hitchcock et al., (2022), who found that PSB enhanced carbon assimilation and water uptake by improving soil structure and microbial activity. Dry biomass followed a similar trend, with P3 producing 159 g, an increase of 44 g compared to the control (115 g). This suggests metabolic stability in dry matter accumulation and resilience under variable environmental conditions.

Table 3. Physicochemical Parameters of Soil

Treatment	Soil pH	C-Organic (%)
P0 (Control)	5.23 ± 0.06a	1.74 ± 0.05a
P1 (PSB)	5.67 ± 0.05b	1.95 ± 0.06b
P2 (Jakaba)	5.73 ± 0.04b	2.02 ± 0.04b
P3 (PSB + Jakaba)	6.05 ± 0.05c	2.21 ± 0.05c

Note: Values followed by different letters indicate significant differences (Tukey HSD test, $p < 0.05$).

Table 3 shows that the physicochemical quality of the soil improved significantly following the application of PSB and Jakaba bioactivators, particularly under the combined treatment (P3). This improvement contributed substantially to creating a more favorable growing environment for hybrid maize and serves as a key indicator of sustainability in organic farming systems.

Soil pH increased from 5.23 (control) to 6.05 in the P3 treatment. This change reflects the ability of the bioactivators to neutralize soil acidity, thereby enhancing the availability of essential nutrients. Fudjoe et al., (2025) explained that PSB can release bicarbonate ions and other alkaline compounds that neutralize hydrogen ions in acidic soils, which is critical for improving nutrient uptake and root enzyme activity. Furthermore, the organic carbon content increased from 1.74% in the control to 2.21% in the P3 treatment. This 0.47% increase indicates more efficient decomposition of organic matter. Photosynthetic microorganisms have been reported to accelerate organic matter mineralization and increase active carbon content, thereby directly enhancing soil fertility.

The most notable improvement was observed in the cation exchange capacity (CEC), which rose from 17.9 cmol/kg (control) to 25.8 cmol/kg in the P3 treatment – an increase of 7.9 cmol/kg. This value reflects the improved ability of the soil to retain and supply nutrient ions to plants. These results are consistent with findings by Dar et al., (2021), who stated that PSB application can enhance soil aggregation and improve nutrient retention capacity through exopolysaccharide production and increased microbial enzymatic activity.

Table 4. Soil Microbiological Parameters

Treatment	Microbial Population (10 ⁶ CFU/g)	Dehydrogenase (µg TPF/g/h)
P0 (Control)	1.3 ± 0.1a	12.2 ± 0.9a
P1 (PSB)	2.2 ± 0.2b	17.6 ± 1.1b
P2 (Jakaba)	2.5 ± 0.2b	19.1 ± 1.3b
P3 (PSB + Jakaba)	3.4 ± 0.3c	23.4 ± 1.5c

Note: Values followed by different letters indicate significant differences (Tukey HSD test, $p < 0.05$).

Table 4 shows that soil microbiological parameters increased significantly following treatment with bioactivators, particularly in the combined PSB and Jakaba treatment (P3). This treatment resulted in a microbial population of 3.4×10^6 CFU/g, more than double that of the control group (1.3×10^6 CFU/g). This increase reflects the role of bioactivators in enriching the diversity and density of soil microorganisms, which are essential for the decomposition of organic matter and the cycling of key nutrients such as nitrogen and phosphorus (Fidelis et al., 2022).

In addition to microbial population, the P3 treatment also exhibited the highest dehydrogenase enzyme activity at 23.4 µg TPF/g/h, far exceeding the control, which measured only 12.2 µg TPF/g/h. Dehydrogenase is a crucial biological indicator of microbial respiration and overall soil health. According to (Lee et al., 2021), increased activity of this enzyme indicates active microbial metabolism, which directly contributes to the transformation of organic matter and the enhancement of nutrient availability in organic soils.

Overall, the combined PSB and Jakaba treatment (P3) had the most significant positive effect on plant productivity and the quality of the growing environment. These improvements were evident in agronomic parameters (plant height, leaf number, fresh and dry biomass), soil physicochemical properties (pH, organic carbon, CEC), and microbiological indicators (microbial population and enzyme activity). These findings support the idea that the application of locally based microbial bioactivators is an effective strategy for enhancing soil fertility and ensuring the sustainability of organic farming systems (Wikurendra et al., 2022).

Integration of Findings and Recommendations

The bibliometric analysis revealed that research on Photosynthetic Bacteria (PSB) has grown significantly since 2015, particularly in relation to its use as a biofertilizer and soil improvement agent. Keywords such as *photosynthetic bacteria*, *biofertilizer*, and *soil health* dominated the co-occurrence map, reflecting a global research focus centered on nutrient efficiency and the enhancement of soil physicochemical properties. However, to date, no direct connection has been identified between PSB and local microorganisms such

as *Jakaba* (*Corallomycetella repens*) in terms of publication trends, citation networks, or bibliometric keyword analysis.

The experimental findings in this study explicitly address this gap. The combined application of PSB and *Jakaba* (P3 treatment) not only resulted in the highest agronomic performance in hybrid maize but also significantly improved soil pH, increased organic carbon content, and stimulated both microbial

population and enzymatic activity. Although *Jakaba* has yet to be widely documented in international scientific literature and databases, the empirical results of this study demonstrate its remarkable potential as a locally sourced fungal-based bioactivator or decomposer. Therefore, this research opens new avenues for integrating photosynthetic microorganisms and indigenous fungi as an innovative approach in the development of biologically based organic agriculture.

Table 5. Synthesis of Experimental and Literature Findings

Element	Global Literature (Bibliometrics)	Experimental Results (Local)
PSB	Major biofertilizer	Improves yield and soil fertility
<i>Jakaba</i>	Not Indexed in Scopus	Produces significant agronomic and microbiological effects
Combination	Rarely discussed in publications	Demonstrates synergistic interaction and optimal effectiveness
Tropical Organic Context	Mostly dominated by studies in East Asia	This study conducted in the tropical ecosystem of Sigi, Central Sulawesi

By understanding the specific composition and functional mechanisms of Photosynthetic Bacteria (PSB) and *Jakaba* (*Corallomycetella repens*), it can be concluded that their combination not only demonstrates empirical effectiveness but also possesses complementary biological functions. PSB contributes to nitrogen fixation, phytohormone production, and enhanced nutrient availability, while *Jakaba*, as a local endophytic fungus, supports the decomposition of organic matter and strengthens microbial activity in the soil through the release of lytic enzymes and secondary metabolites. This synergistic interaction creates a more stable and productive soil microbial ecosystem. Therefore, the integration of both in organic land bioactivation systems is not only technically feasible but also scientifically justified for broader development and future research focus.

Conclusion

The combination of Photosynthetic Bacteria and *Jakaba* has been proven effective as an eco-friendly bioactivator that enhances the growth of hybrid maize and improves soil quality under organic farming systems. Bibliometric analysis revealed a growing global research trend on PSB, whereas *Jakaba* remains underrepresented in international literature. This study bridges that gap by integrating both microorganisms as an effective, locally sourced bioactivator solution. It successfully connects global scientific literature with local field practices and suggests the development of microbial-based technologies to support the future sustainability of organic agriculture.

Acknowledgments

This research is part of the outcomes of the *Bertani untuk Negeri* Program organized by Edefarmers Foundation International. The authors would like to express their gratitude for the support, guidance, and opportunities provided by Edefarmers during the execution of this study. Appreciation is also extended to the Agricultural Extension Center (BPP) Mantikole and the Farmers' Group of Kaluku Tinggu Village, Dolo Barat Subdistrict, Sigi Regency, for their cooperation, technical assistance, and facilities during field experimentation. Special thanks are also conveyed to all colleagues who contributed to data analysis and the preparation of this manuscript.

Author Contributions

Author 1 was responsible for the research idea formulation, field experimentation, data collection and analysis, result visualization using VOSviewer and Design Expert, and drafting the initial manuscript. Author 2 contributed to the literature review, writing of the introduction, and refinement of the manuscript structure. Author 3 assisted in the methodology section and processing of experimental results. Author 4 contributed to language revision, formatting according to APA reference style, and compiling the reference list. Author 5 was in charge of final editing, scientific content validation, and coordinating team communication. All authors have read and approved the final version of the manuscript for journal submission.

Funding

This research was financially supported by Edefarmers Foundation International through the *Bertani untuk Negeri* Program 2024, particularly for fieldwork and supporting facilities. Additional costs related to data analysis, result visualization, and manuscript preparation were partially self-funded by the first author.

Conflicts of Interest

The authors declare no potential conflicts of interest financial, professional, or personal that could influence the objectivity, validity, or interpretation of the research findings.

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