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Utilization of antagonistic bacteria and fungi for inducing resistance in red chili and cayenne pepper in Tanjung Dayang Utara

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ABSTRACT

Plant health problems caused by pests and diseases remain a significant challenge for farmers, especially in cultivating red curly chili and cayenne pepper. Conventional reliance on synthetic pesticides raises environmental and economic concerns. This community service program aimed to enhance farmers' knowledge in using biological agents as alternatives to synthetic pesticides to strengthen plant resistance. The program was carried out in Tanjung Dayang Utara Village, Ogan Ilir, through stages of preparation, implementation, evaluation, mentoring, and monitoring. Methods included lectures and demonstrations on using Pseudomonas fluorescens and Trichoderma sp. through seed soaking and soil or foliar application. A total of 50 farmers attended, receiving both theoretical and practical training. The evaluation was conducted in three phases: pre-, during, and post-activity. Previous approaches relied heavily on synthetic pesticides, while recent innovations emphasize ecological pest management using microbial antagonists. The outcomes showed a high level of enthusiasm and improved understanding among farmers regarding natural pest resistance mechanisms. Farmers were able to practice the propagation and application of beneficial microbes supported by educational materials. The program reduced farmers' dependency on chemical inputs and contributed to sustainable agricultural practices. This model using replicable in similar agroecosystems facing pest and disease issues. The main problem addressed was farmers' limited knowledge and skills in utilizing biological control agents as environmentally friendly alternatives. The implementation consisted of preparation, training through lectures and demonstrations, field practice, and evaluation. The results indicated measurable improvements, including increased knowledge based on evaluation scores and reduced reliance on chemical pesticides.

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KEYWORDS
Biological control
Microbial agents
Chili farming
Sustainable agriculture
Pest resistance

1. Introduction

Agricultural sustainability remains a critical concern, particularly in rural areas where farming is the primary livelihood [1], [2]. In many developing regions, smallholder farmers rely heavily on synthetic pesticides to manage crop diseases, especially in high-value crops such as chili [3], [4]. The overuse of synthetic pesticides has led to environmental degradation, including soil pollution, contamination of water resources, and disruption of beneficial insect populations [5]. Moreover, farmers are frequently unaware of the long-term consequences of chemical usage, both for ecological balance and human health. These

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challenges emphasize the urgent need to introduce environmentally friendly alternatives for plant disease management.

Scientific literature has shown that biological control agents offer a promising solution to the overdependence on synthetic pesticides [6]. Beneficial microbes such as Pseudomonas fluorescens and Trichoderma sp. have been extensively studied for their antagonistic properties against plant pathogens [7]. These microbes stimulate plant defense mechanisms, compete for nutrients, and produce antimicrobial compounds [8], [9]. Their integration into farming practices is also associated with improved soil health and crop resilience. However, despite these advantages, farmers' adoption rate of biological control agents remains relatively low due to limited exposure and lack of training.

Current studies have mainly focused on laboratory trials or controlled greenhouse environments where biocontrol agents demonstrate high efficacy [10], [11]. However, transferring these findings to real-world farming scenarios presents different challenges. The lack of farmer awareness and minimal access to training and demonstrations hinders the practical implementation of biocontrol technologies. There is a significant knowledge gap between scientific advancements and on-the-ground applications in the agricultural sector. Therefore, developing a structured educational program that brings laboratory innovations to the fields is necessary.

Community service programs offer a platform to bridge the gap between research institutions and farming communities [12]. These initiatives deliver practical knowledge and foster trust between scientists and local stakeholders. Community service can enhance farmers' effectiveness and acceptance of sustainable farming technologies by involving farmers in hands-on training [13]. In this context, it becomes essential to tailor the content to the local context, considering the types of crops, common diseases, and traditional practices of the target area. This ensures the program's relevance and applicability to the day-to-day challenges faced by farmers.

The originality of this initiative lies in its community-centered approach to plant disease management. Unlike previous interventions that rely solely on disseminating leaflets or lectures, this program integrates direct demonstrations and participatory learning [14]. Farmers are engaged through field trials and practical sessions, allowing them to observe and evaluate the performance of biological agents in real-time. Such experiential learning is expected to reinforce knowledge retention and encourage behavioral change. It also empowers farmers to make informed decisions based on evidence and field-based observations.

This program also considers the increasing demand for sustainable agricultural practices that align with national and global environmental goals. By reducing the reliance on synthetic inputs, the approach supports Indonesia's commitment to the Sustainable Development Goals (SDGs), particularly Goal 2 on Zero Hunger and Goal 12 on Responsible Consumption and Production. Promoting the use of biocontrol agents aligns with the principles of agroecology and enhances the resilience of food systems against climate-related risks. Additionally, it contributes to local food safety by minimizing chemical residues on agricultural products. These broader impacts underline the program's potential beyond its immediate objectives.

The village of Tanjung Dayang Utara in Ogan Ilir Regency was selected as the site for this program based on its high level of chili production and frequent issues with plant diseases. Farmers in this area have expressed concern over declining yields and increasing costs related to pesticide use. Preliminary surveys indicated that many were unaware of biological alternatives or lacked the resources to explore them. Furthermore, the partner community consists of smallholder chili farmers characterized by limited access to agricultural extension services, low adoption of environmentally friendly technologies, and dependence on conventional pest control practices, which collectively represent the core problems addressed in this program. In addition, preliminary field data indicated that yield losses due to plant diseases could reach significant levels during peak infection periods, reinforcing the urgency of implementing alternative plant protection strategies. This strategic opportunity to introduce a community-based intervention that is both timely and relevant. The program seeks to build local capacity and long-term sustainability through collaboration with local agricultural stakeholders.

Furthermore, the program integrates local wisdom and existing farming practices to ensure cultural compatibility. While introducing new technology, it respects and acknowledges traditional methods, encouraging farmers to compare and evaluate both. This approach reduces resistance to change and builds a foundation for sustained adoption. Farmers are not passive recipients but active participants in

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experimentation and learning. The synergy between scientific knowledge and local experience enhances the innovation's adaptability.

The program's long-term vision is to create a model that can be replicated in other rural communities facing similar challenges. Documentation and evaluation will be conducted to track progress, identify barriers, and refine strategies for broader dissemination. Partnerships with local universities, agricultural extension agents, and community leaders will ensure continuity beyond the initial implementation. By establishing networks of trained farmers, the program aims to build a community of practice that supports sustainable farming. Ultimately, it aspires to contribute to a more significant movement toward ecological agriculture in Indonesia.

Based on the aforementioned considerations, the main objective of this community service initiative is to improve farmers' knowledge in addressing plant disease problems through alternative solutions beyond synthetic pesticide use. Specifically, this activity aims to increase farmers' understanding of biological control agents, enhance practical skills in the application of Pseudomonas fluorescens and Trichoderma sp., and promote the adoption of environmentally friendly pest management practices in chili cultivation. The project provides training, demonstration plots, and continuous mentoring on applying biological control agents such as Pseudomonas fluorescens and Trichoderma sp. The approach combines scientific rigor with practical relevance, ensuring impact and sustainability. In doing so, it meets the farming community's immediate needs and long-term aspirations. The initiative is formally titled "Utilization of Biological Agents in Reducing the Use of Synthetic Pesticides in Chili Cultivation in Tanjung Dayang Utara Village, Ogan Ilir Regency".

2. Method

This community service initiative was implemented through five structured phases: preparation, implementation, evaluation, mentoring, and monitoring. The methods were aimed to solve the farmers' challenges in combating pests and diseases while responding to the objective of promoting the use of biological agents in chili farming. To ensure clarity and scientific rigor, the methodological stages are arranged sequentially and systematically (step-by-step), explicitly describing the planning, implementation, and evaluation phases as recommended.

2.1. Preparation Phase

During the preparation phase, administrative requirements were arranged, and initial communication was conducted with the village head and local chili farmers in Tanjung Dayang Utara. A preliminary orientation was also carried out, including pest and disease observation and assessment of current farming practices. Coordination meetings with the academic team (lecturers and students) ensured alignment of activities. This stage represents the planning phase, in which all preparatory activities were systematically designed to support the effectiveness of the subsequent implementation stage.

2.2. Implementation Phase

In the implementation phase, a combination of lectures and practical training was delivered to introduce biological control agents. Farmers participated in seed treatments using Pseudomonas fluorescens at varying soaking durations (0, 2, 4, 6 hours) and concentrations (0, 3, 6, 9 ml/l), and were trained in applying Trichoderma sp. through spraying (0, 2, 4, 6 ml/l) and soil embedding (0, 10, 20, 30 mg/l). All treatments were applied to both curly red and cayenne chili varieties to test resistance effects. This stage represents the implementation phase, where all planned activities were executed in a structured and step-by-step manner to ensure effective knowledge transfer and technical application.

2.3. Evaluation Phase

The evaluation phase included pre- and post-activity assessments, involving observation of pest resistance, participant response surveys, and an analysis of knowledge gains. A demonstration plot (demplot) was used to monitor field effectiveness of treatments. This stage represents the evaluation phase, which was conducted systematically to assess the effectiveness of the program based on measurable indicators, including knowledge improvement, farmer participation, and field performance outcomes.

- The mentoring phase encouraged independent farmer practice with ongoing support. Leaflets were distributed to assist dissemination and replication of techniques among local communities. This mentoring stage complements the implementation phase by strengthening farmer capacity through continuous guidance and practical reinforcement.

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- In the monitoring phase, follow-up visits assessed the sustained application and impact of the intervention. Farmers' participation included group discussions, training, material preparation, antagonist media production, and field demonstrations. This monitoring stage ensures continuity of the program by evaluating long-term adoption and sustainability of the implemented practices.

2.4. Data Collection and Analysis Techniques

Data were collected through direct field observations, focus group discussions (FGDs), pre- and post-activity surveys, and documentation of farmer participation. Samples were selected purposively based on their active involvement in chili farming. The instruments used (e.g., survey forms, observation sheets) were validated by peer review and field testing to ensure reliability. Descriptive qualitative analysis was applied to categorize knowledge gains and behavioral changes, while qualitative data indicators measured participation and satisfaction levels. Success indicators were assessed using predefined evaluation criteria. The program took place in Tanjung Dayang Utara Village, Ogan Ilir Regency. It was carried out over a one-month period, including a one-day training, one-day demonstration, and follow-up monitoring (Fig. 1).

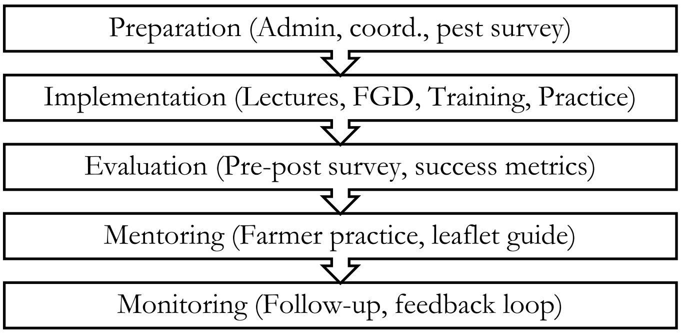

Fig. 1. The Implementation of Community Service

3. Results and Discussion

3.1. Preparation Stage

In the preparation stage, the PKM team carried out three activities to ensure the effectiveness and readiness of the community empowerment program.

3.1.1. Needs Analysis

A needs analysis was conducted by observing and identifying the conditions and challenges faced by farmers in Tanjung Dayang Utara Village, Ogan Ilir, South Sumatra. Field visits were organized and coordinated with the village head and community representatives (Fig. 2).

Fig. 2. Field visits of Tanjung Dayang Utara Village, Ogan Ilir, South Sumatra

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Most farmers were not introduced to the benefits of antagonistic bacteria and fungi as organic pest control alternatives. This information was gathered through informal interviews and group discussions. The farmers' dependence on synthetic pesticides and fertilizers was a significant concern that contributed to high production costs. Consequently, the use of natural alternatives such as antagonistic bacteria and fungi was not yet known. The information obtained from this needs analysis became the foundation for preparing the extension materials. In addition, the results of the needs analysis were quantitatively reflected in the identification of key farmer constraints, particularly the high dependency on synthetic inputs and the limited knowledge of biological control agents, which directly informed the initial objectives of the program to improve farmers' understanding and adoption of eco-friendly pest management strategies.

3.1.2. Problem Analysis

A problem analysis was also conducted to formulate relevant and practical solutions. The key problem identified was farmers' lack of awareness and skills in utilizing natural resources such as beneficial microorganisms. Farmers tended to perceive bacteria and fungi as harmful without recognizing their potential as antagonistic agents. Based on this problem, a training module and demonstration plan were designed to introduce the use of Bacillus thuringiensis and Trichoderma sp. These natural agents were proposed as eco-friendly substitutes to reduce synthetic pesticide usage. This problem formulation was also aligned with the program objectives, where the lack of farmer knowledge and skills was translated into measurable targets, including increasing farmer awareness and practical capacity in utilizing antagonistic microorganisms as sustainable pest control solutions.

3.2. Implementation Stage

The implementation stage was carried out over four months, from July to October 2024, involving various activities focused on knowledge transfer and demonstration of bio-agent applications (Fig. 3). Several sequential activities were executed, including permission requests, field visits, material preparation, counseling, demonstrations, evaluation, and reporting. The activities were attended by approximately 50 participants, mostly young farmers and key community figures. These participants were involved in counseling sessions and hands-on demonstrations. This form of participatory training has been recognized as a highly effective method in rural agricultural extension. Base on research of this method fosters active engagement and direct practice among farmers [13]. The involvement of young farmers, in particular, was considered a strategic step, as they possess greater adaptability and openness to innovation in agricultural practices [15], [16]. The implementation outcomes were also documented in a measurable manner, including the number of participants involved (approximately 50 farmers) and their level of engagement during training activities, which served as indicators of program effectiveness in achieving its initial objectives.

Fig. 3. Knowledge transfer and demonstration of bio-agent applications

The training and outreach activities were conducted through visitation and live demonstrations. A total of 50 farmers participated, most of whom were members of local farming groups. These farmers were invited to attend a series of sessions in which they were introduced to beneficial microorganisms through lectures and practical demonstrations. The effectiveness of this approach was reflected in observable

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participant responses, where active involvement during demonstrations and discussions indicated an increase in knowledge transfer, supporting the program's objective of enhancing farmer capacity in biological pest control applications. During the main session, farmers were gathered at the training site and informed about the advantages of using antagonistic bacteria and fungi in crop cultivation. It was emphasized that microorganisms traditionally viewed as harmful could be re-purposed to enhance plant immunity against pests and diseases. Three hundred chili seedlings, aged two weeks, were distributed and used during the practical sessions. *Trichoderma* sp. was demonstrated through a step-by-step process involving sterilized corn media and starter culture preparation.

The cultivation process was shown until the media turned green, indicating successful fungal growth (Fig. 4). For *Bacillus thuringiensis*, a direct field application was demonstrated. The use of *Trichoderma* sp. and *Bacillus thuringiensis* as biological agents had been recognized in previous studies as effective and environmentally friendly alternatives for managing plant pathogens and pests, thereby reducing the dependency on synthetic pesticides [17], [18].

A three-phase evaluation was also conducted to assess participant comprehension and application. The implementation included continuous evaluation activities. Evaluations were conducted in three stages: pre-extension, during the extension, and post-extension. Pre-training evaluations involved simple questionnaires and open discussion. During the training, participation levels were observed. Post-training evaluations were conducted weekly for four weeks to monitor the growth and health of tomato and chili plants treated with weed-based organic pesticides. The evaluation results provided measurable evidence of program impact, as improvements in plant growth and health during the four-week observation period indicated the successful application of the introduced bio-agents, thereby linking the outcomes directly to the program's initial goals.

Fig. 4. Demonstration process involving sterilized corn media and starter culture preparation

The lecture and discussion sessions were followed by a demonstration on preparing and applying *Trichoderma* sp. Clean corn was sterilized by steaming, ground, and spread into three cm-thick layers. Spores of *Trichoderma* sp. were diluted in water and applied to the media using sterile tools. The mixture was packed into plastic bags and left open. After one week, green coloration indicated that the fungus had multiplied successfully and was ready to be applied by seed soaking or soil drenching. Meanwhile, *Bacillus thuringiensis* was directly applied in the field without fermentation.

The knowledge gained was expected to be disseminated by the participants to other farmers in the area. The involvement of young farmers and influential community members was intended to accelerate the adoption of organic farming methods. The counseling sessions, demonstrations, and active discussions stimulated high enthusiasm among the participants. Many asked about microbial species, production techniques, and field application methods. The application of these bio-agents had not previously been introduced to the community. Farmers were surprised to learn that certain microorganisms could serve as pest deterrents. Such bio-agents were found to reduce dependency on costly synthetic pesticides and fertilizers. Participants saw this cost-efficiency as a significant advantage. This finding also represents a tangible impact on community partners, as farmers began to recognize practical and economic benefits from adopting biological control methods, indicating a shift in perception and decision-making toward more sustainable agricultural practices.

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Based on observations during the training, the farmers expressed high enthusiasm. They actively engaged in Q&A sessions, asking about types of effective fungi and bacteria, methods of cultivation, and field application techniques. The training also targeted young farmers aged between 30–40 years who had the potential to disseminate the knowledge further. Influential community leaders were also involved to ensure broader impact and sustainability. Furthermore, the involvement of young farmers and community leaders contributed to strengthening the dissemination of knowledge within the community, which can be interpreted as a multiplier effect of the program's impact on local agricultural practices. The PKM program succeeded in introducing new methods for plant protection through low-cost and eco-friendly means. *Trichoderma* sp. and *Bacillus thuringiensis* were considered a practical alternative to reduce production costs and promote sustainable agriculture in the village. An impact analysis on the participating farmers revealed improvements not only in knowledge but also in technical skills and readiness to adopt bio-agent applications, demonstrating that the program successfully enhanced community capacity in sustainable pest management.

As a result, the farmers reported increased awareness and expressed the need for continued training in future programs. The implementation of this activity was well received and has provided a strong foundation for further development of organic pest control practices in the community. This aligns with the findings of [19], who emphasized the role of microbial bio-agents in enhancing sustainable agriculture and reducing chemical inputs, and with [20], who reported increased farmer participation and knowledge transfer through participatory training models in organic farming communities. Moreover, the results of this activity indicate that the program achieved its intended objectives, as reflected by measurable participation, improved plant performance, and positive behavioral changes among farmers, highlighting the effectiveness of the intervention in supporting sustainable agricultural development.

4. Conclusion

The main issue identified was the farmers' lack of knowledge regarding the use of antagonistic microbes such as Trichoderma sp. and Bacillus thuringiensis in controlling plant pests and diseases. Therefore, community empowerment activities were carried out to enhance farmers' understanding and practical skills in utilizing environmentally friendly and cost-effective biological control methods. This PKM activity successfully introduced new knowledge and skills, as evidenced by the active participation of farmers and the improvement in their understanding through direct training and evaluation. Specifically, the results demonstrated a measurable increase in farmers' knowledge and practical ability to prepare and apply microbial-based biocontrol agents in the field. In addition, the tangible benefits experienced by partners included improved pest and disease management practices, reduced dependency on chemical pesticides, and increased awareness of sustainable agricultural techniques. Future programs are advised to focus on assisting farmers in producing microbial agents independently to ensure sustainability. Furthermore, it is recommended to develop a structured follow-up program, including continuous mentoring, monitoring, and the establishment of farmer groups focused on microbial production to strengthen long-term sustainability. This activity has contributed a new method and model of microbial-based community empowerment in agriculture, supported by field data and observations.

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Declarations

Author contribution. All authors contributed equally as the main contributors to this paper. Each author was actively involved in community service activities' preparation, implementation, evaluation, and

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documentation stages. All authors read and approved the final version of the manuscript for submission and publication.

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