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SPEKTA

Empowering Women's Groups through IoT-Based Aeroponic Automation for Sustainable Agriculture on Limited Land in Sidoarjo

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ABSTRACT

Background: The decline of agricultural land in Sumokembangsri Village due to industrial expansion has reduced local food production. This program aimed to enhance the community's capacity, particularly PKK women's groups, in cultivating vegetables on limited land through IoT-based aeroponic automation.
Contribution: This community engagement initiative contributes to strengthening women's roles in smart agriculture, improving technological literacy, enhancing production and management competencies, and offering a scalable model of aeroponic-based smart farming for land-constrained areas.
Method: The program was conducted for six months and involved 78 active participants. Activities included socialization, hands-on training, IoT-based aeroponic installation, mentoring, and evaluation. Knowledge and management skills were assessed using structured questionnaires, while data were analyzed with descriptive statistics to measure learning outcomes and program effectiveness.
Results: Participants showed substantial improvement in technical and managerial competencies. Knowledge of aeroponic principles increased from 40% to 88.85%, while understanding of its impact on crop quality and yield rose from 38.49% to 87.69%. Management capabilities, including resource management, team coordination, and

organizational governance, also improved, with average scores rising from 66–71% to 94–98%. Participants successfully operated IoT-based systems and demonstrated strong motivation for sustaining smart farming practices.
Conclusion: The integration of IoT-based aeroponic automation with community-based empowerment effectively enhances agricultural productivity, strengthens local capacity, and supports sustainable food production. The program achieves its objective of empowering PKK groups through smart technology and provides a replicable model for similar semi-urban rural communities facing land limitations.

1. Introduction

The Indonesia, an archipelagic nation rich in natural resources, has a substantial portion of its population relying on agriculture, particularly in rural areas [1], [2]. According to data from the Central Statistics Agency (BPS) for 2022, approximately 40.64 million individuals are employed in the agricultural sector. This significant workforce underscores agriculture as a key sector in supporting the nation's economic growth. The abundance of natural resources, coupled with the large agricultural workforce, highlights the sector's critical role in driving Indonesia's economic development [3]. However, amidst the dynamic shifts in the economic landscape, the agricultural sector faces numerous challenges and obstacles. Economic incentives often drive individuals to seek faster and easier sources of income, a trend reflected in the decision of some community members to sell agricultural land to corporations, which then repurpose it for non-agricultural uses [4]. This conversion of agricultural land can have significant implications for the economy, food security, and the environment [5], [6]. Consequently, the increasing trend of land conversion over the years necessitates focused attention, particularly from the government, in preparation for Indonesia's Golden Vision 2045 [7].

Sumokembangsri Village is located in the Balongbendo District, Sidoarjo Regency. The area covers a total of 262.03 hectares with an average elevation of 20 meters above sea level. The village has a population of approximately 4,567 residents, distributed across 1,499 households [8]. The majority of the residents in Sumokembangsri Village rely on agriculture as their primary livelihood. Currently, over 85% of the agricultural land is dedicated to rice cultivation, which has a harvesting period of approximately three months. The remaining land is used for growing vegetables, which can be harvested in about 30 days. However, vegetable cultivation faces significant challenges, particularly with pests and inconsistent water supply, which often leads to crop failures. Consequently, farmers are increasingly seeking opportunities for quicker and easier income compared to their previous earnings from

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agriculture. One approach they have adopted is selling their farmland to companies, especially for industrial purposes [9].

The conversion of agricultural land into industrial zones indeed presents opportunities for economic growth and job creation, which are essential steps towards broader prosperity for the community. According to interviews with village officials in Sumokembangsri, industrial development began around 2010 and has continued to expand to the present day. This shift was largely driven by inconsistent income and frequent losses due to extreme weather conditions. The direct impact on local farmers has been the loss of both land and livelihood. This loss represents more than just a job transition; it signifies a profound social and economic transformation within Sumokembangsri Village. Former farmers, who once depended on their land, are now compelled to seek alternative livelihoods, such as starting small businesses like eateries and laundry services, to adapt to the changing environment. This transition has also affected the sustainability of agriculture, which was previously a hallmark of Sumokembangsri, known for its rice and fresh vegetables.

In 2018, the Balongbendo District recorded a total of 36 industries, including 16 large-scale industries and 20 medium-sized industries [8]. The number of industries in the district is expected to continue increasing over time. Figure 1 illustrates the changes in land use in Sumokembangsri Village, reflecting the number of rice fields and factories from 2013 to 2024. The reduction in agricultural land has a direct impact on the loss of farming livelihoods, particularly affecting women who are often homemakers with limited income. Additionally, this shift has led to a decline in the productivity of staple foods such as rice and fresh vegetables.

Furthermore, the establishment of factories has negatively affected environmental quality, including soil, water, and air temperatures. Research conducted by the author indicates that the initial characteristics of soil intended for cultivation are crucial for achieving optimal plant fertility and harvest yields. However, areas near factories show higher levels of heavy metals, which adversely impact soil fertility. [10]. This is evident from the declining crop yields in rice fields located near factories, where the results are suboptimal. As a result, some farmers have chosen to forgo their farming activities by selling their land for industrial development.

Based on the knowledge base in the agricultural sector, which serves as the primary asset for initiating agricultural conservation efforts, women in rural areas have been cultivating plants in front of their homes or along roadways [11]–[16]. However, the yield is typically sufficient only for family consumption due to limitations in space and planting holes. Subsequently, some village communities have adopted hydroponic farming in their front yards. This approach provides an opportunity for individuals to contribute to the agricultural sector despite having limited land, while also helping to enhance local food security and gradually improve their economic conditions [17]–[20]. Over time, however, hydroponic farming has exhibited several drawbacks. One major issue is the turbidity of the nutrient solution due to the growth of algae and undesirable bacteria, necessitating regular replacement of the nutrient solution [21].

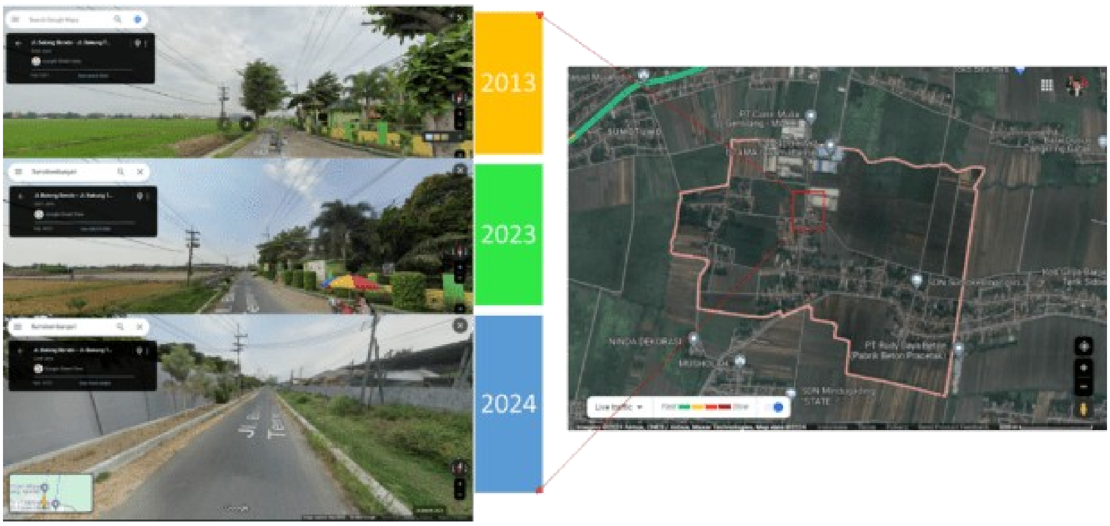

Figure 1. Condition of Agricultural Land in Sumokembangsri Village from 2013 to 2024.

This adds complexity to the maintenance of hydroponic systems, as monitoring water quality and replacing the nutrient solution become crucial activities that require additional time and cost. In some cases, the turbidity of the nutrient solution can impact plant health and productivity, as well as increase the risk of plant diseases [22], [23]. This issue is illustrated in Figure 2, which shows the hydroponic results of a group of residents who integrated hydroponics with aquaculture. The outcomes were unsatisfactory due to several plant diseases and a lack of optimal understanding and management of the hydroponic methods, resulting in subpar results.

Figure 2. Current Status of Hydroponic and Aquaculture Integration with Dysfunctional Systems and Average Land Potential for Development.

The primary objective of this initiative is to empower the PKK groups as women actively involved in transforming social dynamics and strengthening local agricultural wisdom in Sumokembangsri Village. The cultivation on limited land using both traditional soil-based methods and hydroponics will be enhanced through the implementation of aeroponic technology, integrated with automation and Internet of Things (IoT) systems. This approach aims to provide valuable knowledge in advanced agricultural techniques and foster food self-sufficiency [24]–[26].

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However, previous community-based agricultural programs have rarely combined gender empowerment with high-tech solutions like IoT-driven aeroponics, especially in semi-urban rural settings. Moreover, there is limited research on how such technological interventions can be sustainably managed by local women's groups, particularly in terms of production, maintenance, and commercialization. This highlights a clear research gap in combining smart agriculture with gender-focused community empowerment.

Therefore, the specific objectives of this study are: (1) to enhance the agricultural and technological capacity of women through IoT-based aeroponics; (2) to strengthen their roles in production management, maintenance, and marketing; and (3) to contribute to the achievement of the Sustainable Development Goals (SDGs), particularly in promoting gender equality, climate-resilient agriculture, and poverty reduction through women-led agri-business models in Sumokembangsri Village.Furthermore, this initiative will improve the management roles of the PKK groups in the application of technology. It will ensure the sustainability of the benefits by organizing production teams, maintenance, and marketing, with a view toward future commercialization.

2. Method

This To enhance the technical capabilities of partners in production, the strategy employed involved knowledge and technology transfer through a mentoring approach focused on implementing IoT-based aeroponic planting methods. This approach aimed to motivate PKK groups to independently adopt these techniques, facilitating their growth and development. The program engaged 88 participants, with 78 attending the activities. The entire process, including introduction, mentoring, evaluation, and harvest, was conducted over a period of six months. Measurement instruments included questionnaires to assess knowledge and management skills, while data analysis was performed using descriptive statistics.

In terms of improving management aspects, partners will receive long-term training in web-based management applications. This training is designed to address manual challenges and improve overall evaluation processes for the PKK groups, positioning them for future commercialization prospects. It is anticipated that the training and dissemination provided will be well-received, offering significant benefits and being effectively implemented by the partners, as illustrated in Figure 3.

The stages of implementing the empowerment activities of the PKK Group in Sumokembangsri Village, Balongbendo, Sidoarjo, Indonesia were designed in a structured and comprehensive manner, starting from the preparation stage to the final evaluation to ensure the achievement of the expected goals as described in Figure 4 and the technology design was depicted in Figure 5.

The method section structure should: describe the materials used in the study, explain how the materials were prepared for the study, describe the research protocol, explain how measurements were made and what calculations were performed, and state which statistical tests were done to analyze the data. The method must clear with the location and time of the research, the population, and sample of the study, the research variables, and the research data. The method of your manuscript also mentions the detail of your community engagement program.

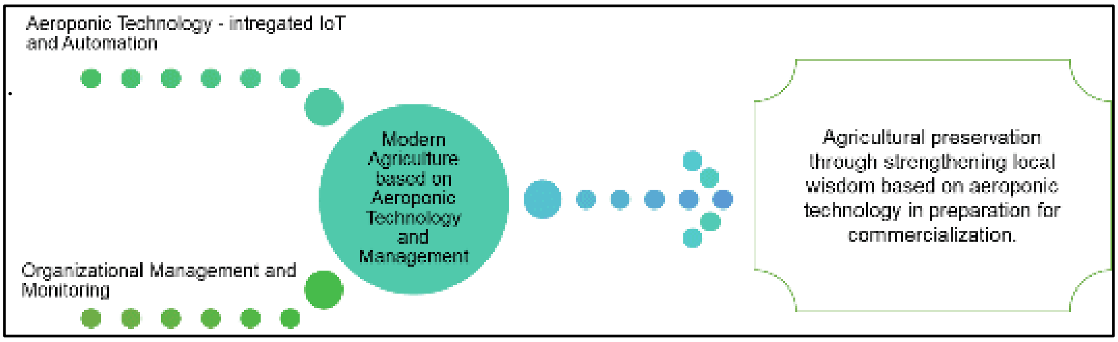

Figure 3. Methods and Target Goals for Mentoring PKK Groups in Sumokembangsri Village

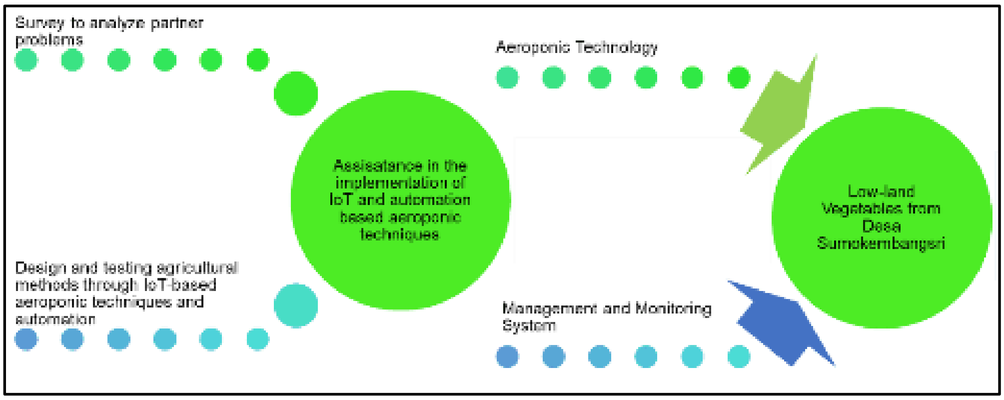

Figure 4. Concrete stages in overcoming problems in the Production and Management aspects of the PKK Group in Sumokembangsri Village.

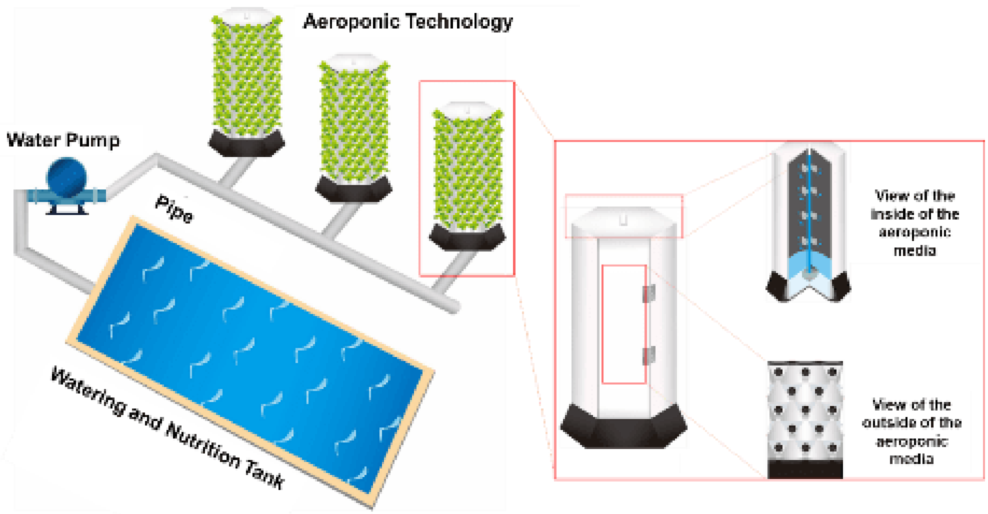

Figure 5. Aeroponic Technology Design.

To enhance participants technical skills, a mentoring approach was used to transfer knowledge on IoT-based aeroponic planting. Out of 88 participants, 78 attended the six-month

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program covering introduction, mentoring, evaluation, and harvest. Questionnaires monitored progress, and data were analyzed using descriptive statistics to measure training effectiveness.

3. Results and Discussion

The dissemination of information is divided into two stages. The first stage is aimed at the PKK groups as the primary partners directly involved in implementing the technology. This phase includes Focus Group Discussions (FGD) designed to help these partners understand potential mapping and the application of modern technologies as boosters for agricultural productivity. Specific topics covered include aeroponic planting methods based on IoT and modern management through applications. This targeted engagement is intended to ensure that the PKK groups are well-prepared to adopt and utilize these advanced techniques effectively. The outreach sessions were attended by the village head, village officials, the PKK chairperson, PKK members, and residents of Sumokembangsri Village as shown in Figure 6. This inclusive attendance ensured that key stakeholders and community members were present, facilitating a broad dissemination of information and encouraging collective engagement in the discussion and implementation of the aeroponic technology.

Figure 6. Focus Group Discussion and Sosialization Session in Desa Sumokembangsri

The second stage involves outreach to the general public. This stage includes presenting information about Automation IoT-based aeroponic planting through a presentation titled "Efforts to Enhance Local Agricultural Wisdom Quality and Limited Land Utilization Through Automation and IoT-Based Aeroponic Planting in Sumokembangsri Village, Balongbendo

District, Sidoarjo Regency." The goal is to inform and educate the broader community about the benefits and applications of this technology, thereby fostering greater awareness and potential adoption among local residents.

During the outreach sessions, participants were engaged in kinetic learning activities to deepen their understanding of aeroponic technology. This hands-on approach facilitated active participation, allowing attendees to experience the technology firsthand and ask questions about its application. The interactive format enabled participants to better grasp the concepts and effectively explain the technology, fostering a more comprehensive and practical understanding of aeroponics with the material.

The program consists of training, technology implementation, mentoring, and evaluation. The training on aeroponic farming methods combines theoretical and practical approaches. The theoretical component includes explanations of the advantages of aeroponic methods, necessary equipment, framework preparation steps, spraying techniques using Automation and Internet of Things (IoT) technology, and simple procedures for analyzing crop quality in Figure 7. Meanwhile, the practical training involves steps for constructing the framework, setting up IoT-based spraying schedules, and performing analytical techniques. The goal of this activity is to ensure that partners gain a comprehensive understanding and become proficient in applying aeroponic planting methods.

Figure 7. Counseling of Aeroponic Technology Implementation-based Automation and Internet of Things (IoT) and Its Management.

The aeroponic farming system, designed as vertical racks made from durable, weather-resistant materials, offers a scalable and efficient solution suitable for diverse environments. Each 1m x 1m rack with a 2m height is easy to assemble and manage by local communities, promoting wider adoption. Equipped with nozzles for uniform delivery of water and nutrients, this system supports the cultivation of various horticultural crops such as leafy greens, lettuce, tomatoes, and chili peppers. Beyond improving crop quality and accelerating growth compared to conventional methods, the system contributes to sustainable agricultural development by optimizing land use, reducing water consumption, and minimizing environmental impact [21], [24], [26], [27]. Its adaptability and resource efficiency align with global goals to enhance food security and promote environmentally friendly farming practices, demonstrating potential for replication in other regions facing similar challenges.

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The automation system is controlled by a panel integrated with the equipment circuitry, with a general setting of 30 minutes of watering every 2 hours. Additionally, users can operate and control the system via IoT technology. The IoT system can be managed remotely from a smartphone, with no specific distance limitations [26]. The equipment requires continuous Wi-Fi connectivity for 24 hours to facilitate IoT control. Users can independently set and adjust the timing and duration of watering based on the needs of the plants. In case of IoT issues, the automation can still function without Wi-Fi by relying solely on the pre-set watering schedule. Both methods of control are user-friendly and accessible, ensuring that planting can be conducted safely, easily, and efficiently.

The participation of PKK groups in Figure 8, as target partners in the program includes several key aspects: (i) partners play an active role as participants throughout the implementation of the program, (ii) partners provide the necessary facilities and infrastructure for aeroponic planting, such as planting areas, water distribution systems, reservoirs, and water pumps, and (iii) partners are the primary users of the technological products developed through this program.

Figure 8. Aeroponic System Control Group (left) and Aeroponic Technology Support Team (Lecturers and Students) (right).

The evaluation of production and management aspects will be assessed using questionnaires distributed to participants. Out of the 78 individuals who took part in the training, more than 70% completed the questionnaires. These responses will be used for further analysis to gauge the effectiveness of the training and to identify areas for improvement in both production techniques and management practices [15], [16]. The questionnaire addressed several key areas related to aeroponic technology. It assessed participants' basic knowledge of aeroponics by asking if they understood the fundamental principles of an aeroponic system and could explain its impact on the quality and yield of vegetable crops. It also evaluated practical skills in operating aeroponic technology, inquiring about their proficiency in setting up and maintaining the system and their ability to identify and resolve common issues. Additionally, the questionnaire gauged motivation by exploring how the training or capacity-building program had enhanced their capability to manage an aeroponic system. The result of production evaluation was shown in Figure 9 and management evaluation in Figure 10.

Before the counseling sessions, respondents demonstrated a foundational understanding of the principles underlying aeroponic systems, with an average score of 40%. This score reflects a basic level of knowledge about how aeroponic systems operate. Similarly, their ability to articulate how these systems affect the quality and yield of vegetable crops was moderately developed, with an average score of 38.49%. These preliminary scores suggest that while respondents had some grasp of the core concepts, there was room for significant improvement in both their theoretical understanding and their practical insights into the impact of aeroponic systems on crop production.

After the counseling sessions, there was a notable enhancement in respondents' understanding and analytical abilities. The average score for comprehension of the fundamental principles of aeroponic systems increased to 88.85%. This substantial improvement indicates a deepened and more comprehensive grasp of the system's mechanisms. Additionally, the ability to elucidate the effects of aeroponic systems on the quality and yield of vegetable crops also saw a significant rise, with the average score reaching 87.69%. These post-counseling scores reflect a marked advancement in both theoretical knowledge and practical application, demonstrating the effectiveness of the counseling in enhancing overall expertise in aeroponic systems.

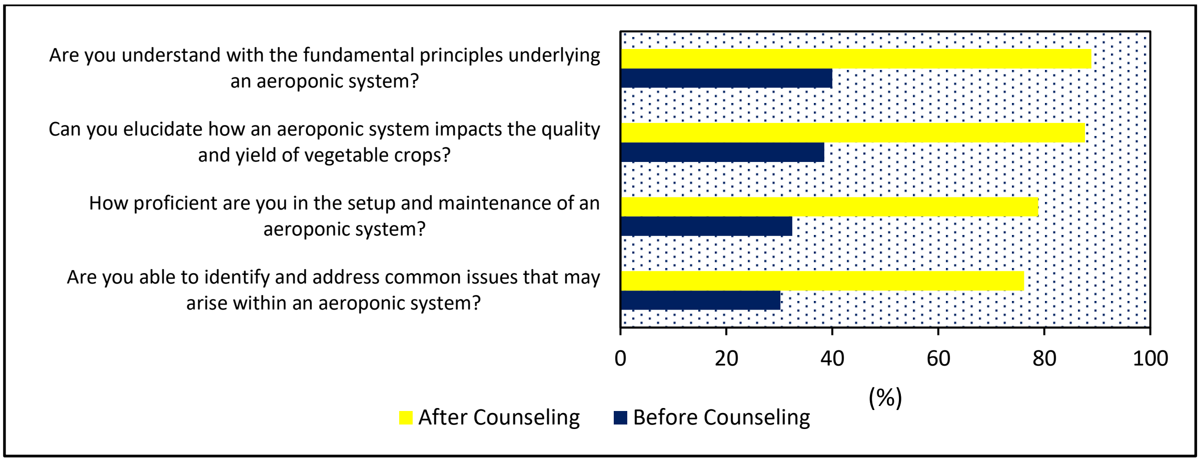

Figure 9. Questionnaire Result on Enhancing Partner Empowerment in Production Aspects.

Before counseling, participants showed a solid understanding of managing resources (financial, human, and material) for aeroponic vegetable production, with an average score of 69.23%. Their effectiveness in managing the team or department responsible for this production was slightly higher, averaging 70.77%. Their grasp of their own roles and responsibilities in achieving organizational goals within the aeroponic context was reflected in a score of 66.15. Understanding of the organizational structure and governance related to aeroponic vegetable production was also reasonably strong, averaging 67.69%.

Following counseling, there was a marked improvement across all areas. Participants' ability to manage resources effectively increased to an average score of 97.14%, and their management effectiveness of the team or department rose to 95.71%. Their understanding of their roles and responsibilities in achieving organizational goals significantly improved to 94.29%, while their comprehension of the organizational structure and governance related to aeroponic production saw the highest increase, reaching an average score of 98.57%. These

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results highlight the counseling's effectiveness in enhancing participants' skills and knowledge in all critical aspects of aeroponic vegetable production.

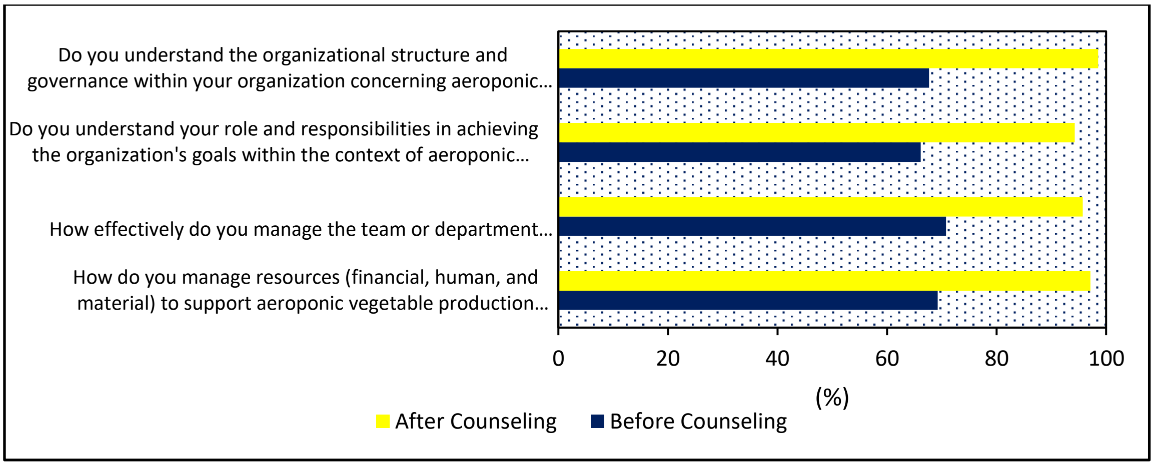

Figure 10. Questionnaire Result on Enhancing Partner Empowerment in Organizational Management Aspects

As seen in Figure 11, the sustainability of training and mentoring in aeroponic technology significantly boosts motivation within the community. Currently, the effective utilization of aeroponic technology, from planting processes to its application, demonstrates a high level of engagement and adoption. This ongoing support not only educates individuals on the technical aspects of aeroponics but also fosters a proactive approach among farmers [28]. They are increasingly responsive to technological advancements, adapting and refining the systems to better suit their needs [29], [30].

Figure 11. Sustainability of Activities Post-Dissemination and Councelling.

Furthermore, the community's involvement extends beyond mere adoption to active improvements in the growing medium used in aeroponic systems. This proactive approach illustrates a deepening understanding and commitment to optimizing the technology for better results. As a result, there is a continuous cycle of learning and enhancement, leading to more efficient and effective aeroponic practices. The integration of feedback and iterative improvements reflects the significant impact of sustained training and mentoring in advancing technological proficiency and innovation in agriculture.

4. Conclusion

In conclusion, automation and aeroponic IoT technology were introduced to improve vegetable cultivation on limited land through a program involving training, technical support, and management guidance for members of the PKK group. Among the 78 participants, over 70% completed evaluation surveys, showing a knowledge increase in aeroponic IoT principles by 48.85% and understanding of its impact on crop quality and yield by 49.2%. Management competencies also improved significantly, with average scores rising by 28–32%. These results demonstrate that integrating IoT-based aeroponic automation with local agricultural practices effectively boosts productivity, strengthens community capacity, and provides a scalable model for smart farming in land-constrained areas. Despite challenges like internet connectivity, this approach contributes to sustainable agriculture and enhanced food security.

Future community engagement programs and research may explore the long-term economic impact of IoT-based aeroponics on household income and local markets, especially when managed by women's groups. Further studies can also examine system optimization, such as integrating renewable energy for IoT operation, developing locally produced low-cost components, and expanding crop varieties suitable for automated aeroponics. Additionally, research on digital literacy strengthening, commercialization pathways, and environmental monitoring (e.g., water usage efficiency and carbon footprint reduction) would support broader implementation and sustainability of smart farming initiatives.

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