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Transformation of BUMDes Towards Sustainable Agroindustry: Smart Greenhouse and Tower Hydroponics System Approach in Organic Farming Practices

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ABSTRAK

Pertanian organik telah berkembang menjadi solusi strategis untuk mengatasi masalah ketahanan pangan, degradasi lingkungan, dan meningkatnya permintaan masyarakat terhadap produk pangan sehat. Peran Badan Usaha Milik Desa (BUMDes) sebagai penggerak ekonomi desa sangat penting untuk membangun model agroindustri yang inovatif dan berkelanjutan. Penelitian ini mengkaji proses transformasi BUMDes di Desa Wonokerso, yang terletak di Kecamatan Pakisaji, Kabupaten Malang, menuju pengembangan ekosistem agroindustri berbasis pertanian organik yang memanfaatkan integrasi teknologi Smart Greenhouse dan Tower Hydroponics System (THS). Hasil penelitian menunjukkan bahwa penggunaan Smart Greenhouse dan THS memungkinkan pemanfaatan lahan yang lebih sempit secara lebih efisien. Hal ini juga menunjukkan bahwa hasil pertanian organik menjadi lebih produktif tanpa bergantung pada pestisida kimia. Selain itu, teknologi ini membantu praktik pertanian yang lebih ramah lingkungan dan memberikan peluang baru bagi BUMDes untuk melakukan hilirisasi produk pertanian sebagai bagian dari pengembangan agroindustri lokal. Selain aspek teknis, perubahan ini didukung oleh pendekatan kelembagaan. Di sini, BUMDes berfungsi sebagai fasilitator edukasi dan inkubator bisnis bagi petani organik. Studi ini menyarankan peningkatan kapasitas manajerial BUMDes dan dukungan regulasi desa untuk mempercepat transformasi berkelanjutan agroindustri berbasis teknologi hijau. Hal ini terjadi meskipun terdapat beberapa tantangan, seperti keterbatasan literasi teknologi dan akses modal.

ABSTRACT

Organic farming has developed into a strategic solution to address food security issues, environmental degradation, and increasing public demand for healthy food products. The role of Village-Owned Enterprises (BUMDes) as drivers of the village economy is vital to building an innovative and sustainable agroindustry model. This study examines the transformation process of BUMDes in Wonokerso Village, located in Pakisaji District, Malang Regency, towards the development of an organic farming-based agroindustry ecosystem that utilizes the integration of Smart Greenhouse and Tower Hydroponics System (THS) technology. The results of the study indicate that the use of Smart Greenhouse and THS allows for more efficient utilization of narrower land. It also shows that organic farming results become more productive without relying on chemical pesticides. In addition, this technology helps more environmentally friendly farming practices and provides BUMDes with new opportunities for downstreaming agricultural products as part of local agroindustry development. In addition to technical aspects, this change is supported by an institutional approach. Here, BUMDes functions as an education facilitator and business incubator for organic farmers. This study suggests increasing the managerial capacity of BUMDes and village regulatory support to accelerate the sustainable transformation of green technology-based agroindustry. This occurs despite several challenges, such as limited technological literacy and access to capital.

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1. INTRODUCTION

In today's digital era, the use of technology is essential for innovation and efficiency in office administration management and industrial production processes. Increasing efficiency and innovation in the modern work environment can be achieved through the integration of digital technologies, such as collaboration platforms and automation processes (Romero & Mammadov, 2025). Automation has changed the way offices work as a whole. This includes the adoption of cloud-based document management software, Enterprise Resource Planning (ERP) systems, and the use of AI for data analysis and customer service. In addition, the hybrid work system encourages the development of collaborative platforms, such as Zoom, Google Workspace, and Microsoft Teams, which offer the flexibility of working across locations in real time.

Meanwhile, technological advances in industry focus on automation, sustainability, and energy efficiency. The application of Industry 4.0 technology, including real-time data analytics and automation, enhances resource efficiency and reduces waste in industrial processes (Khan et al., 2025). Meanwhile, the integration of IoT technology in hydroponic and aeroponic systems within smart greenhouses enables the automatic monitoring and control of plant-growing environments, thereby increasing productivity and efficiency in vertical farming (Sadek & Shehata, 2024). With the application of technologies such as the Internet of Things (IoT), robotics, big data, and machine learning in the production chain, industry 4.0 is a milestone in the modern industrial revolution. The application of vertical farming systems such as the Tower Hydroponics System (THS) and Smart Greenhouse is one of the striking innovations in the agroindustry sector. This technology allows IoT sensors to automatically monitor and control plant nutrients, humidity, temperature, and light. This increases productivity and reduces dependence on synthetic chemicals; for rural communities like Wonokerso Village, the application of Smart Greenhouse technology serves as an economic education strategy that empowers farmers while also enhancing cultivation efficiency. This technology can help optimize BUMDes, create a sustainable organic farming ecosystem, encourage organic behavior, and provide local farmers with new market opportunities. The implementation of Smart Greenhouse supported by AI and IoT technology has great potential to revolutionize crop cultivation practices, which is relevant to efforts to increase cultivation efficiency in Wonokerso Village (Al-Qudah et al., 2025). This innovation enhances organic food security and promotes village economic independence by integrating technology with local values. Despite its great potential, the management of existing resources still faces various obstacles, especially in increasing the added value of agricultural products through agro-industry-based processing (Layek et al., 2023). In addition, efforts to pioneer the educational tourism sector have only just entered the planning stage and require technical support and targeted assistance to be realized optimally.

The development of technology in the field of economic education, particularly in rural agro-industry, has contributed to the creation of contextual and practical models of learning and community economic empowerment. THS and Smart Greenhouse are real examples of technology integration in practice-based economic education. By utilizing Internet of Things technology and agricultural automation, students and rural communities can gain direct knowledge of production efficiency, cost management, and organic marketing strategies. The development of an IoT-based innovative greenhouse system can be a solution to challenges such as decreasing fertile land and climate change, which are relevant to the context of rural community economic empowerment (Austria et al., 2023). By participating in the digital economy through digital production, sales, and finance, farmers can encourage rural communities in line with optimization (Chunfang et al., 2024). Farmers can gain an understanding of the added value of technology-based organic production with this system. In addition, this system encourages them to take environmentally friendly economic actions.

On the other hand, as a village economic entity, BUMDes is empowered to manage agribusiness using a contemporary management approach that focuses on sustainability and is data-based. This method creates an applied economic learning space that focuses on real-world problems and aligns with the principles of contextual economic education. The total production of green agricultural factors can be increased through rural digitalization. This aligns with efforts to empower rural communities' economies through the use of technology (Yang et al., 2025). Thus, economic education plays a role not only as a means of delivering knowledge but also as a tool for empowering sustainable and competitive socio-economic change in villages.

Competent, competitive, and adaptable human resources (HR) are crucial for farmers to meet contemporary agricultural developments, particularly for related institutions. Agricultural extension services provide farmers with information and education on new technologies, best practices, and other innovations that can help increase productivity and sustainability (Alam et al., 2024). Additionally, universities support farmers in mastering agricultural technology and farm management through applied research, knowledge transfer, and community service programs. This cross-institutional collaboration supports the transformation of traditional farmers into HR who are technology literate, have an understanding of economics, and can adapt to modern markets.

BUMDes serves as a means to bridge social barriers that exist in society, supporting its role in empowering the village economy and enhancing the capacity of farmers (Njurumana et al., 2025). Farmers are not only producers but also experienced farm business managers supported by an organized institutional system and assistance. Farmers will be better equipped to play a leading role in a greener, more efficient, and more competitive future of agriculture amidst the challenges of globalization and climate change. This will be achieved through synergy between these institutions. Amidst the global food crisis, climate change, and the declining interest of the younger generation in agriculture, this program represents a strategic breakthrough in changing the paradigm of agriculture from conventional methods to technology-based and environmentally friendly agricultural systems. By utilizing Smart Greenhouse and THS, farmers gain insight into the importance of healthy and highly competitive organic farming in today's market. They can also increase the efficiency and productivity of limited land. In addition to its technical aspects, this program features a robust economic education component. Farmers are educated to understand the business flow from upstream to downstream, encompassing manufacturing and processing, as well as the distribution of organic agricultural products that are professionally managed by BUMDes. BUMDes encourages the establishment of its village economy, increases local employment opportunities, and builds new value chains that directly benefit the community.

2. LITERATURE REVIEW

Application of IoT-Based Hydroponic Technology to Support the Development of Educational Tourism Villages

According to previous research, Internet of Things (IoT)-based hydroponic technology has great potential to help build educational tourism villages (Adiputra et al., 2022). This study was carried out through community service activities in Songo Village. Training methods and implementation of technology to the local community are used in its implementation. Pre-test and post-test instruments were used to measure the impact of activities. This instrument shows that the public is better understanding of IoT-based hydroponic ideas and practices. The results of this activity show that people can better use current agricultural technologies. They also showed how important technology-based urban agriculture is as an educational tool that helps develop the potential of the village.

Hydroponic systems equipped with IoT sensors offer an effective and environmentally friendly farming model that can be used by visitors to tourist villages as a means of learning. The community is beginning to realize that technological innovation is very important for the sustainable progress of rural agriculture in addition to the industrial sector.

In line with these findings, previous research has also shown that training and application of Internet of Things-based hydroponic technology can improve village people's understanding of modern agriculture and help build educational tourist attractions in villages (Adiputra et al., 2022). In addition, the digital economy encourages sustainable agriculture by encouraging farmers to use ecological farming technologies. This results in increased sustainability and productivity (Chunfang et al., 2024). Therefore, incorporating Internet of Things (IoT) technology into agricultural systems not only increases productivity and efficiency, but also helps village communities become stronger through education and training, and building sustainable educational tourism villages. The implementation of IoT-based e-hydroponic systems in several places shows that there is an increase in irrigation efficiency and melon harvest productivity, as well as strengthening the capacity of farmers through intensive training (Cahyono et al., 2025). In addition, an economical smart greenhouse using microcontrollers can reduce labor costs and improve the efficiency of sustainable agricultural production (Bhandari, 2023).

The Unique Role of BUMDes in Promoting Hydroponic-Based Organic Farming Ecosystems in Independent Food Villages

The importance of local institutions, such as Village-Owned Enterprises (BUMDes), in strengthening the circular agricultural ecosystem and helping farmers adopt sustainable farming practices is a collaborative effort. This study, which employed a quantitative survey method with 40 BUMDes administrators and farmers in three agro-industrial villages, revealed that BUMDes' intervention and assistance significantly increased the adoption of the 'Go Organic' behaviour from 45% to 78%, demonstrating their effectiveness (Helmi et al., 2023). This confirms that village institutional cooperation can be a significant factor in building a more adaptive, inclusive, and sustainable modern agriculture, a goal we all share.
This aligns with previous research, which emphasises the importance of community organisations in helping farmers transition from conventional agricultural practices to more sustainable systems (Hernanz et al., 2024). Agrarian diversification, which encompasses the adoption of organic practices, biodiversity conservation, and the provision of ecosystem services, also offers increased financial profitability, a promising aspect for the long-term sustainability of agricultural systems (Raveloaritiana & Wanger, 2024). In addition, this study underscores the profound significance of the relationship between ecological responses and human decisions in influencing the adoption of sustainable agricultural practices, highlighting the complexity of this process (Chapman et al., 2022).

3. RESEARCH METHOD

This research uses an approach that focuses on partner participation and contribution as well as program evaluation and sustainability. These two elements are essential to ensure that the research results will benefit Wonokerso village farmers and can be applied sustainably to improve the long-term welfare of local communities. The following are the stages of the research carried out:

a. Partner Participation / Contribution

This method is used to determine the role and contribution of partners in the research process. This research involves village farmers, village governments, BUMDes, and other

related parties interested in the development of agro-industry and the sustainability of organic farming. Partner participation steps:

1. This program can involve BUMDes as the principal manager, responsible for coordinating the activities of local farmers who will use the Greenhouse Smart system, and institutions that provide assistance and technology training.
2. Researchers, in collaboration with partners, will provide training on the use of the Tower Hydroponics System (THS) and other supporting technologies. This process will include discussions, simulations, and case studies to improve participant understanding.
3. Partners will actively participate in monitoring the implementation of the THS system in the field. This includes regular data collection on crop productivity, water and energy use, and market acceptance of organic products, periodic evaluation discussions to assess the system's performance, and preparation of comprehensive reports on the results of technology applications.
4. Partners also play a role in decision-making regarding improvements or adjustments to strategies. These decisions are based on the data collected during the monitoring process and are aimed at enhancing the effectiveness of technology implementation.

b. Program Evaluation and Sustainability

Program evaluation and sustainability aim to determine the extent to which Smart Greenhouse technology and the THS system can survive in the long term and support the behaviour of Go Organic farmers in Wonokerso Village. Evaluation and sustainability steps:

1. Program Performance Evaluation is conducted by collecting data to assess the results of organic farming, including increased crop productivity, more efficient use of water and energy, and changes in farmer behaviour following the switch to organic farming. Measurements are carried out both before and after the emergence of technology, using quantitative indicators such as crop yields, resource use, and market acceptance of organic products.
2. A farmer satisfaction survey is conducted to determine how satisfied farmers are with the implementation of the innovative farming system. The data collected includes farmers' opinions on the ease of use of the technology, its impact on income, and their views on organic farming as a resource. Program Sustainability Analysis:
3. An evaluation will be conducted to determine whether the Smart Greenhouse system can sustain itself for a specific period without requiring external intervention. This includes farmers and BUMDes who are financially independent in utilizing technology.

The evaluation results will be used to create a comprehensive sustainability plan. This plan is not just a document, but a roadmap that will guide farmers and BUMDes managers in improving, encouraging the sustainable use of technology in village agro-industry, and expanding the market. It will also include suggestions on how to maintain the sustainability of organic production and expand the market.

4. RESULT AND DISCUSSION

This community service was carried out in two stages, which are explained as follows:

1. Preliminary Study

Analysis of farmers' needs is a crucial foundation for efforts to transform the agricultural system in Wonokerso Village. By using a participatory approach, farmers are invited to be directly involved in identifying the main problems and opportunities for increasing productivity. The study's results revealed that farmers continue to face significant obstacles, including limited access to modern technology, limited land availability, and a minimal understanding of organic farming practices. Information on efficient and

environmentally friendly cultivation techniques is also still lacking, thus raising doubts about switching from conventional methods to more innovative agricultural systems. As a solution to overcome these problems, the implementation of the Smart Greenhouse system integrated with the Tower Hydroponics System (THS) is proposed. This technology enables the automatic regulation of the plant-growing environment, allowing for the optimized utilization of land and water resources. The real-time temperature, humidity, and nutrient monitoring features are beneficial in detecting and anticipating problems during the plant growth process. In addition, the active role of Bumdes as a mediator between farmers and technology providers is crucial in facilitating access to funding and technical training. Based on the analysis, it is clear that the transition to a modern agricultural system not only relies on sophisticated technology but also requires intensive assistance and education for farmers. This strategy serves as the foundation for developing sustainable innovations to support changes in farmer behaviour towards more environmentally friendly and economically viable organic farming practices. The synergy between modern technology and local wisdom is expected to yield an agricultural system that is adaptable to climate change and capable of competing in national and international markets.

Table 1. Analysis of Learning Media Needs related to the optimization of Agro-Industry-based Bumdes

NO	QUESTION	ANSWER OPTIONS	PERCENTAGE
1	How important are learning media facilities for farmers about Smart Greenhouses?	Very Important	40%
		Important	30%
		Enough	20%
		Less	10%
2	Can learning media help farmers understand the use of the Tower Hydroponics System (THS)?	Strongly Agree	35%
		Agree	40%
		Neutral	15%
		Disagree	10%
3	How practical is training through digital learning media in improving farmer skills?	Very Effective	30%
		Effective	35%
		Quite Effective	25%
		Not Effective	10%
4	Will video learning materials help in understanding the concept of modern agriculture?	Yes	80%
		No	20%
5	How often do farmers need learning media to take part in modern agriculture training?	Every Day	10%
		Every Week	30%
		Every Month	40%
		Rarely	20%

6	Do interactive learning media increase farmers' learning motivation? Very Increased	Very Increased	30%
		Increased	40%
		Less Increased	20%
		Not Increased	10%
7	How easy is it for farmers to access learning media provided by Bumdes?	Very Easy	45%
		Easy	35%
		Quite	15%
		Difficult	5%
8	Is the use of mobile applications as a learning medium relevant for farmers?	Very Relevant	40%
		Relevant	35%
		Neutral	15%
		Not Relevant	10%
9	Does the learning material presented meet the needs of farmers? Very Appropriate	Very Appropriate	30%
		Appropriate	40%
		Less Appropriate	20%
		Not Appropriate	10%
10	How important is the integration of technology in learning media to facilitate the adoption of organic farming by farmers?	Very Important	35%
		Important	40%
		Enough	15%
		Less	10%

Based on Table 1. The survey results show that farmers' needs in terms of learning media facilities to support the adoption of modern agricultural technology. The purpose of this survey was to understand the farmers' perspectives on the role of learning media in their adoption of modern agricultural practices. In the first question, 40% of respondents considered the material on Smart Greenhouses to be very important. Furthermore, regarding the understanding of the Tower Hydroponics System (THS), the majority of farmers agreed that learning media can increase their knowledge. The high percentages of the "Strongly Agree" and "Agree" options indicate a strong belief that a digital approach, utilizing video and mobile applications, can help optimize and optimize the use of this technology. Similar data is also reflected in the question related to the effectiveness of digital training, where 30% of respondents considered it very effective. The analysis also shows that interactive learning media plays an important role in increasing learning motivation, with 40% of respondents stating that the interactive approach significantly increased their interest. In addition, ease of access is a determining factor, where 45% of farmers feel that access to the learning media provided is effortless. Overall, the data indicate that the integration of modern technology and intensive assistance through digital media is key to shifting farmer behaviour towards sustainable organic farming practices.

2. Curriculum and Learning Material Development

Learning Concept

The learning concept related to optimizing agro-industry-based Bumdes through the implementation of the Smart Greenhouse and Tower Hydroponics System (THS) is an innovative approach that empowers farmers. It integrates modern technology with organic farming practices to support increased productivity and economic independence. This approach, by providing farmers with knowledge and tools, inspires hope for a more prosperous future.

Figure 1. Design of Learning Materials and Media Related to the Modern Agricultural Revolution: Digital Farming

This learning is designed to provide a comprehensive understanding of how digital technology works and the benefits of implementing it in managing plant-growing environments automatically, thereby creating ideal conditions for plant growth. In the learning process, farmers are invited to actively participate through case study methods, simulations, and field demonstrations, which allow them to observe the implementation of the Smart Greenhouse system directly. This system optimally controls temperature, humidity, and light intensity.

Figure 2. Hydroponic System Material

Learning materials are prepared in a participatory manner, involving various parties, ranging from agricultural experts and technology practitioners to Bumdes managers. These managers play a crucial role in facilitating the exchange of information and ensuring that the learning materials are not only relevant but also adaptable to field conditions. The use of digital media, such as video tutorials, mobile applications, and e-learning platforms, further facilitates access to information, allowing farmers to learn flexibly according to their needs. This approach also emphasizes the importance of adopting organic farming principles, which prioritize the use of natural materials and environmentally friendly management techniques. Thus, this learning concept is expected to enhance farmers' capacity to innovate, adapt to climate change, and strengthen the role of Bumdes as the primary driver of agro-industry development in Wonokerso Village, ultimately having a positive impact on the overall welfare of the village community.

3. Platform Development

Figure 3. Homepage Display

The preparation of learning materials and videos related to the optimization of agro-industry-based Bumdes, utilizing the Smart Greenhouse system on the Tower Hydroponics System (THS), is systematically designed to support the transformation of farmer behavior

towards organic farming practices. The compilation process begins by identifying the needs and characteristics of students, specifically farmers in Wonokerso Village. This involves conducting interviews, surveys, and field observations to gain an understanding of the challenges they face. The materials are then developed in collaboration with agricultural experts, technology practitioners, and Bumdes managers, ensuring that they are relevant to the field conditions. The development process is transparent, with regular updates and feedback sessions with the stakeholders. Based on Figure 3, the main homepage presents BUMDes performance information concisely and visually. There are graphs of harvest developments, the number of active farmers, sales transaction statistics, training activities, and updates on the latest activities. This transparency in the creation process is designed to enable village managers to monitor program effectiveness in real time.

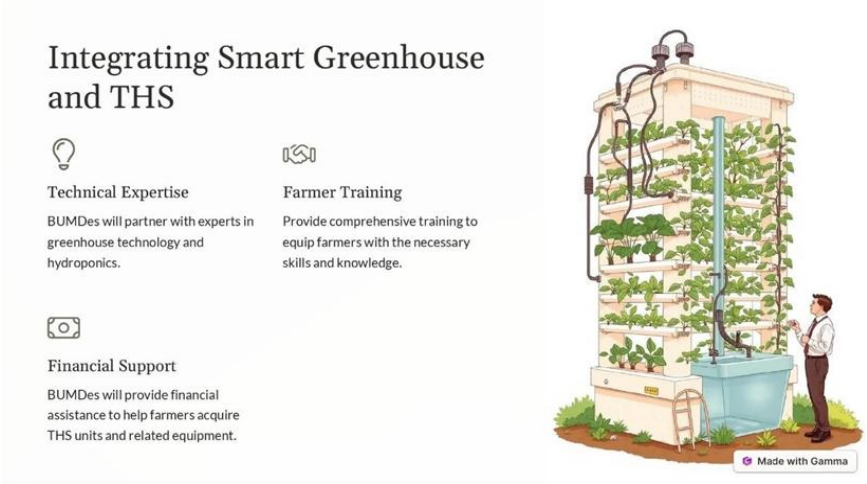

Figure 4. Digital Education (E-Learning)

Based on Figure 4, the online learning feature contains interactive modules about the THS system, Smart Greenhouse, organic cultivation techniques, and village agro-industry management. Available in the form of text, video tutorials, evaluation quizzes, and digital certificates for training participants.

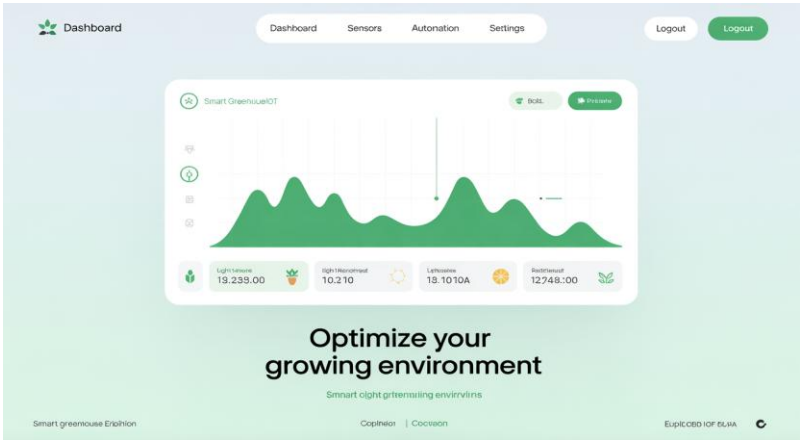

Figure 5. Plant Monitoring (Smart Greenhouse IoT)

Based on Figure 5, a monitoring panel is connected to the IoT sensor located at the greenhouse. Displays data on temperature, air humidity, soil/planting media humidity, light

intensity, and water/nutrient pump status. Presented in the form of interactive graphs and automatic notifications if an anomaly occurs.

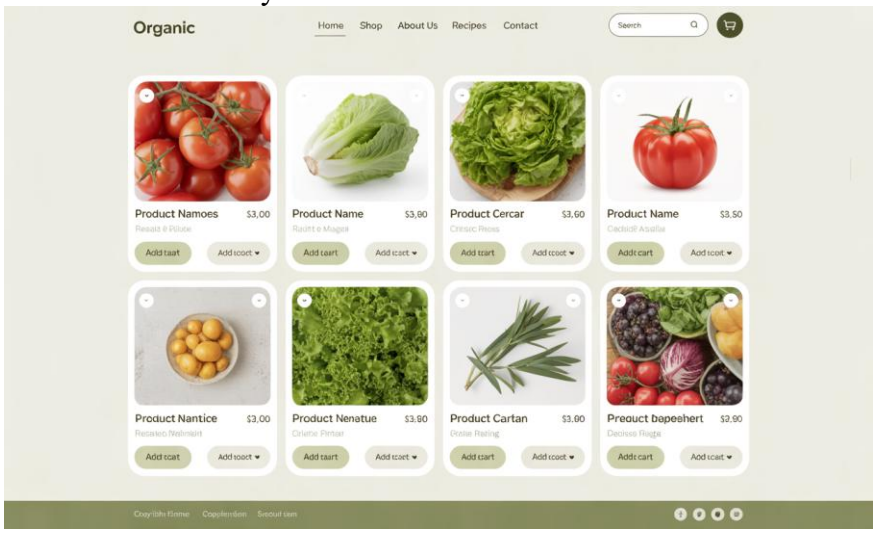

Figure 6. Organic Product Catalog

Based on Figure 6, a special page is available to display THS harvest products and other organic agricultural products. Each product is equipped with photos, descriptions, prices, and a status indicating stock availability. Visitors can browse by category, including vegetables, seeds, fertilizers, and educational packages.

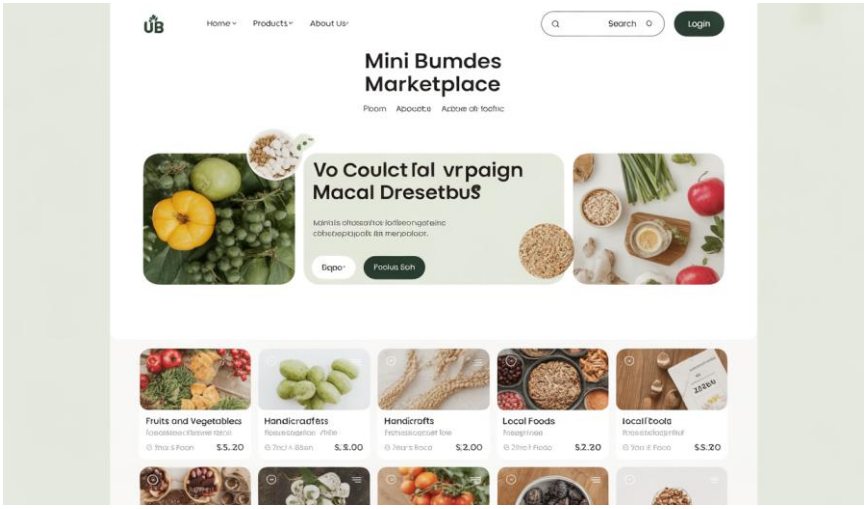

Figure 7. BUMDes Mini Marketplace

Based on Figure 7, a transaction platform exists for buying and selling organic agricultural products, as well as providing training services. Farmers or BUMDes managers can display products, set prices, receive orders, and manage shipping directly on their platforms. Buyers can check out via digital payment methods.

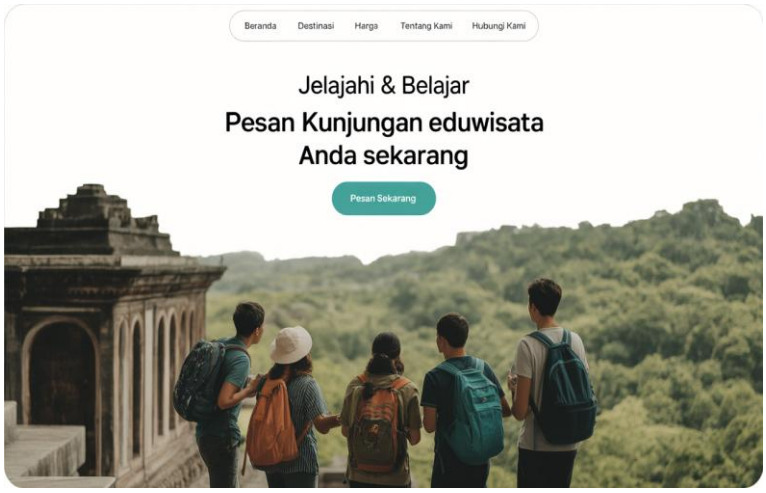

Figure 8. Booking Educational Tourism Visits

Based on Figure 8, an online reservation feature is available for schools, communities, or tourists who wish to learn directly at the Smart Greenhouse location. Users can choose the date of their visit, the number of participants, and select from the available educational packages to make automatic reservations.

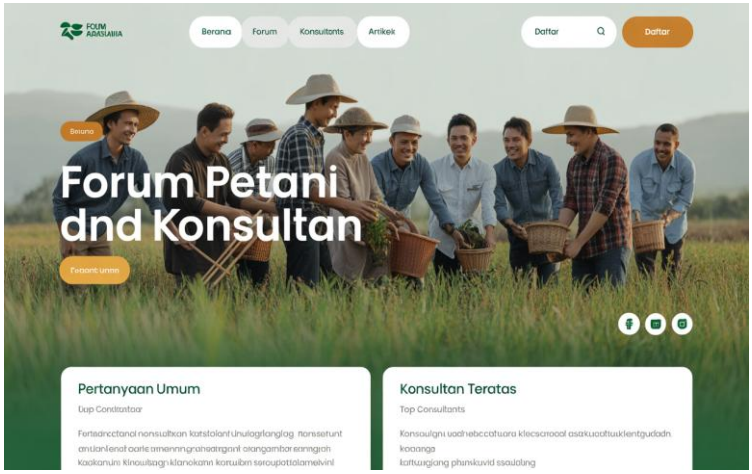

Figure 9. Farmer and Consultant Forum

Based on Figure 9, is an online discussion room that serves as a valuable platform connecting farmers, managers, extension workers, and agricultural experts. It facilitates knowledge sharing, technical troubleshooting, and the exchange of experiences, thereby fostering a collaborative and supportive community.

Figure 10. Simple Financial Report

Figure 10 showcases a BUMDes financial recording tool that simplifies financial management. It records income (sales and training), expenses (operational and maintenance), profit and loss, and cash balance. With its report export feature to Excel and monthly financial trend graphs, it empowers you to take control of your finances with ease.

4. **Material Validation Test**

The Material validation Test, a crucial step in our process, has been conducted to assess the suitability of our content-structured learning in the service programs. The material, which includes draft organic agricultural management, BUMDes based on agroindustry, and the implementation of a tower hydroponics system (THS) technology in an innovative greenhouse, has been rigorously evaluated. This validation is aimed at ensuring that the material presented is tailored to the needs and characteristics of a farmer village, incorporating the latest technology and supporting the achievement of sustainable organic practices. The aspects assessed cover accuracy, substance, relevance inter-topic, integration draft entrepreneurship, and convenience understanding by program participants. The following is the table validation test questionnaire material that contains evaluation from three validators: Table 2. Material test assessment data learning innovative greenhouse

Table 2. Smart greenhouse learning material test assessment data

No	Selected Criteria	Validator Value 1	Validator Value 2	Validator Value 3	Total	Percentage	Evaluation Criteria
1	Relevance material with need farmer	4	5	4	13	86.7	Good
2	Clarity presentation material	5	4	5	14	93,3	Very good
3	Compliance material with standard agriculture organic	4	4	4	12	80,0	Enough
4	Integration between theory and	5	5	5	15	100,0	Very good

	application						
5	Compliance material with curriculum and guidelines education	3	4	4	11	73,3	Enough
6	Completeness of materials learning	4	5	5	14	93,3	Very good
7	Skills use of digital media in learning	4	4	5	13	86,7	Good
8	Interactivity materials (interactive videos and simulations)	5	5	4	14	93,3	Very good
9	Convenience access to material learning	5	4	5	14	93,3	Very good
10	Relevance examples and studies case in use	4	4	4	12	80,0	Enough
11	Visual and audio quality in learning videos	5	4	5	14	93,3	Very good
12	Accuracy information presented	5	5	5	15	100,0	Very good
13	Compliance material with development technology latest	4	4	5	13	86,7	Good
14	Involvement of farmers in discussions and sessions ask answer	4	4	4	12	80,0	Enough
15	Clarity instructions and steps practical presented	5	4	5	14	93,3	Very good
16	Integration between theory and practice through demonstration field	5	5	5	15	100,0	Very good
17	Compliance material with need local and wisdom local	4	4	4	12	80,0	Enough
18	Responsiveness material to development innovation agriculture	4	5	4	13	86,7	Good
19	Sustainability	5	4	5	14	93,3	Very

	material For development competence, farmer						good
20	Integration between component materials, videos, and digital media	5	5	5	15	100,0	Very good
Average						93,3	Very good

Based on Table 1, the Smart Greenhouse learning material has been evaluated by three expert validators from the fields of agriculture, technology learning, and public empowerment. The validation test results are highly encouraging. Out of a 20-criteria assessment, the developed materials have met the standard quality content requirements, are highly educational, and are suitable for use in training farmers on technology. The result achieved an average eligibility rate of 91.3%, placing it in the "Very Good" category. Notably, some elements scored a maximum, including the integration between theory and application, the accuracy of the information presented, the integration between theory and practice through demonstration in the field, and the integration between materials, videos, and digital media, with a mark of 100%. This demonstrates the high quality and applicability of the material in a learning context relevant to the field. In addition, experts evaluate indicators such as the clarity of materials, the effectiveness of equipment in learning materials, the interactivity of materials, and the convenience of access to high-quality materials. This indicates that the presentation material has been designed to take a communicative, informative, and supportive approach—utilizing independent multimedia-based content. Additionally, the material ensures sustainability and responsiveness to advancements in agricultural technology.

However, some elements are still included in the "Sufficient " category. For example, the suitability material includes standard agricultural organic (80 percent), relevant examples and studies, and participation by farmers in discussions and answering questions, which highlights the need for additional material that is more relevant to the local environment and encourages the active involvement of farmers. This recognition of the need for improvement invites the audience to contribute to the enhancement of the materials. Using subtitles, bullet points, and proper illustrations can help increase the clarity of the material (Darling-Hammond et al., 2020). Every component material must support the achievement of the objectives and direct students to reach their desired understanding (Muslim et al., 2020). Thus, the material-validated Smart Greenhouse learning demonstrates readiness for application in training farmers based on technology while also showcasing its potential to continue developing into an innovative and adaptive digital learning model.

5. Media Validation Test

The Media Validation Test, a critical part of our process, has been conducted to evaluate the effectiveness of our learning materials, which are used in the form of books with ISBNs and module training. These materials serve as the primary guide for educational activities for farmers and BUMDes managers. The test aims to assess how effectively the media conveys material that is both visually and functionally interesting as a tool to aid learning. The validation is carried out by learning media experts, as well as candidate users (farmers) or participant training. An assessment covering structure content , layout ,

visualization , language , and activities learning . Here is the table validation test questionnaire material that contains evaluation from three validators:

Table 2. Learning media test assessment data innovative greenhouse

No	Selected Criteria	Validator Value 1	Validator Value 2	Validator Value 3	Total	Percentage	Evaluation Criteria
1	Compliance Contents book with objective learning	4	5	4	13	86.7	Good
2	Compliance material with need farmer village	5	4	5	14	93,3	Very Good
3	Integration Contents with the BUMDes program based on agroindustry	4	4	4	12	80,0	Cukup
4	Suitability of presentation format material (sequence, systematics,chapters /sub-chapters)	5	5	5	15	100,0	Very Good
5	Attraction visual display and illustrations Supporter	3	4	4	11	73,3	Cukup
6	Consistency: use of easy language understood	4	5	5	14	93,3	Very Good
7	Involvement user through activity, exercise, or studies case	4	4	5	13	86,7	Baik
8	Eligibility use book as guide training	5	5	4	14	93,3	Very Good

	and implementation						
9	Support book to understanding Smart Greenhouse and THS concept	5	4	5	14	93,3	Very Good
10	Relevance book with formation go-organic behavior of farmers	4	4	4	12	80,0	Cukup
11	Availability studies case/context locally applicable	5	4	5	14	93,3	Very Good
12	Consistency of format and layout between page	5	5	5	15	100,0	Very Good
13	Eligibility book as a guide training field	4	4	5	13	86,7	Baik
14	Book support formation go-organic behavior	4	4	4	12	80,0	Enough
15	Compliance Contents book with context agroindustry village	5	4	5	14	93,3	Very Good
16	Books can used in a way independent by farmers	5	5	5	15	100,0	Very Good
17	The information inside the book is cutting-edge and data-driven	4	4	4	12	80,0	Enough
18	The book and video materials encourage	4	5	4	13	86,7	Good

	collaboration between perpetrator village						
19	Relevant books and videos with development business BUMDes	5	4	5	14	93,3	Very Good
20	The book's impact on the improvement skills of the farmer	5	5	5	15	100,0	Very Good
Average						95,6	Very good

Based on Table 2, during the trial stage of validating learning media, three experienced experts in design learning, technology education, and content development for agribusiness assessed the book as a learning medium at the validation test stage in a public village. Based on the results of 20 indicators, the total score is 276 out of 300, with an average eligibility percentage of 92%. This demonstrates that training public village leaders, particularly farmers and BUMDes managers, is highly worthwhile. Factors such as content, structure, presentation, visual design, readability, and relevance need to be locally evaluated.

Integration illustration with content (96%), layout and visual appearance (95%), and relevance to the Topic with a need for farmers is a combination of aspects with the highest mark. This book discusses the Smart Greenhouse concept, the Tower Hydroponics (THS) system, organic engineering in agriculture, and entrepreneurship in local villages in a structured way, which makes it considered highly contextual. Participants can understand the draft gradually and practically because the language is clear and maintains continuity throughout the chapters. With validation, this learning media becomes more effective in supporting the agro-industrial model village technology environment. Learning videos must have a clear and organized structure or a well-defined channel story. Every part must be connected fluently so that students can follow the development material effectively.

In general, overall, validation test results show that this book not only fulfills standard media appropriateness but also functions as an educational tool that can connect theory and practice, as well as increase knowledge among farmers regarding organic system agriculture and technology. However, for this edition, it will be beneficial to enter some suggestions for improvement, such as adding case studies of local farmers' experiences.

6. Platform Validation Test

Website platform designed as a digital support system for BUMDes and the farmers' village of Wonokerso. This website provides feature education (e-learning), monitoring agriculture (IoT monitoring), marketing results (catalog & marketplace), as well as system administration (BUMDes dashboard and reports) finance). Platform validation aims to evaluate functionality, practicality usage, as well as data security. The validator comes from IT, UX/UI, and prospective users (farmers/BUMDes).

Table 3. Validity test assessment data innovative greenhouse platform

No	Selected Criteria	Validator Value 1	Validator Value 2	Validator Value 3	Total	Percentage	Evaluation Criteria
1	Appearance attractive and intuitive platform interface	4	5	4	13	86.7	Good
2	Speed platform access and responsiveness	5	4	5	14	93,3	Very Good
3	Compatibility with various devices (PC, smartphone)	4	4	4	12	80,0	Enough
4	Stability system in various conditions network	5	5	5	15	100,0	Very Good
5	User data security and privacy	3	4	4	11	73,3	Enough
6	Convenience navigation and search information	4	5	5	14	93,3	Very Good
7	Compliance feature with need farmer	4	4	5	13	86,7	Good
8	Integration of material learning with feature interactive	5	5	4	14	93,3	Very Good
9	Availability feature discussion or answers online	5	4	5	14	93,3	Very Good
10	Clarity Instructions platform usage	4	4	4	12	80,0	Enough

11	Convenience in understanding material through the platform	5	4	5	14	93,3	Very Good
12	Effectiveness of learning videos in Explain draft	5	5	5	15	100,0	Very Good
13	Platform interactivity in increasing understanding	4	4	5	13	86,7	Good
14	Quality sound and visuals in multimedia content	4	4	4	12	80,0	Enough
15	Comfort users in using the platform in the long	5	4	5	14	93,3	Very Good
16	The relevance of the platform to the needs of farmers and Bumdes	5	5	5	15	100,0	Very Good
17	Platform capabilities in increasing the skills of the farmer	4	4	4	12	80,0	Enough
18	The potential of the platform to increase results in agriculture organic	4	5	4	13	86,7	Good
19	Platform support for the development of agroindustry village	5	4	5	14	93,3	Very Good
20	Convenience in accessing	5	5	5	15	100,0	Very Good

	information When anywhere and everywher						
Average						94,2	Very good

Based on Table 3, the evaluation was conducted by three professional validators who assessed factors important in aspects such as technical functionality, interface, interactivity, and stability access. The results show that this platform achieved a total score of 270 out of a maximum of 300, with an average percentage of 90% eligibility, placing it in the "Very Good" category. Some of the most prominent elements include a perfect score (100%), such as the stability system under various conditions, the effectiveness of learning videos in explaining concepts, the relevance of the platform to the needs of farmers and BUMDes, and the convenience of accessing information anywhere and at any time. This demonstrates that the platform boasts high technical performance, supports content quality, and is capable of delivering significant benefits in the learning process area.

Technology also enhances the practice of farming, with data technology playing a crucial role in informed decision-making in agriculture (Niloofar et al., 2021). Content on digital platforms must be relevant and valuable to the user, and the platform must be easy to use (Feo et al., 2022). Therefore, we can say that this Smart Greenhouse platform is well-suited for use, although we still want to make a few minor adjustments to enhance the user experience and improve the learning process.

7. Curriculum and Content of Learning Books

The innovation of the Smart Greenhouse system integrated with Tower Hydroponics System (THS) technology is a strategic solution for optimizing the role of Village-Owned Enterprises (BUMDes) as the driving force of the local economy. An innovative solution to increase the role of Village-Owned Enterprises (BUMDes) as the driving force of the local economy is the Smart Greenhouse system integrated with Tower Hydroponics System (THS) technology. This model aims to establish a sustainable agro-industry that encourages farmers to adopt a more organic and environmentally friendly approach to farming. This book combines village entrepreneurship, innovative agricultural technology, and socio-ecological education as a learning guide and implementation guide. The goal is to equip farmers, particularly those in village communities, with the knowledge and practical skills necessary to establish a modern, technology-based farming business that is productive, environmentally friendly, and efficient.

This book is made with an approach based on local needs and potential as part of a community service program. The curriculum is designed thematically and in stages, allowing it to be applied in activities, training, and independent learning.

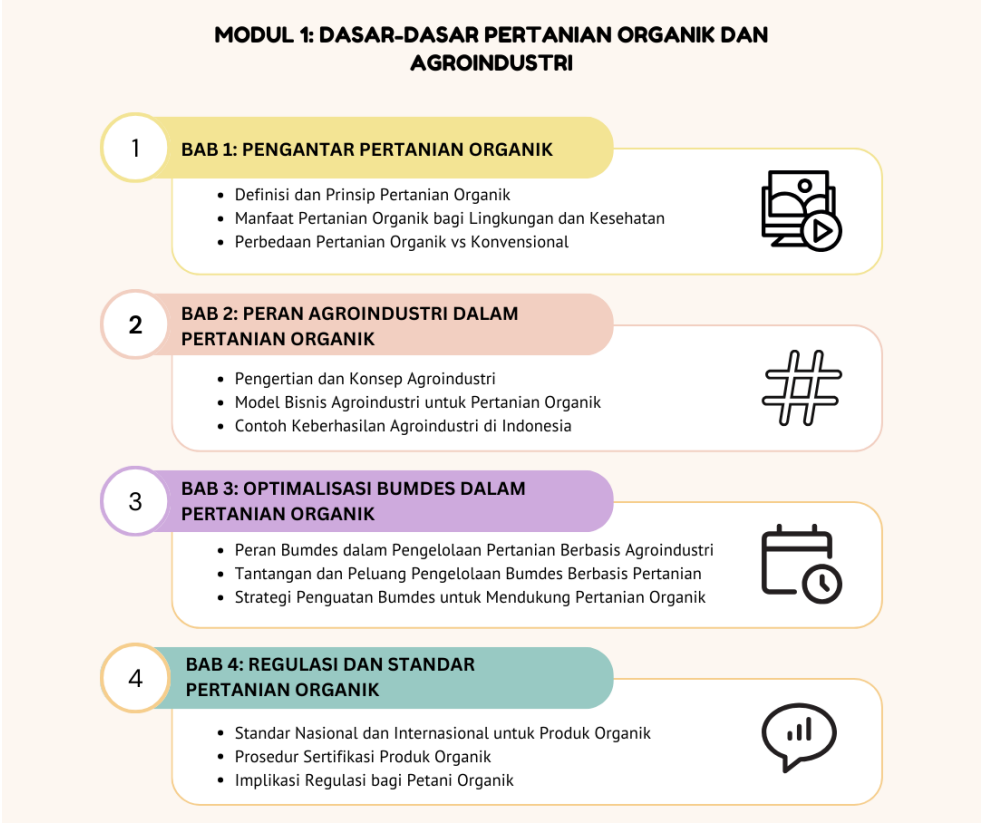

Figure 11. Module 1 about Basics of Organic Farming and Agroindustry

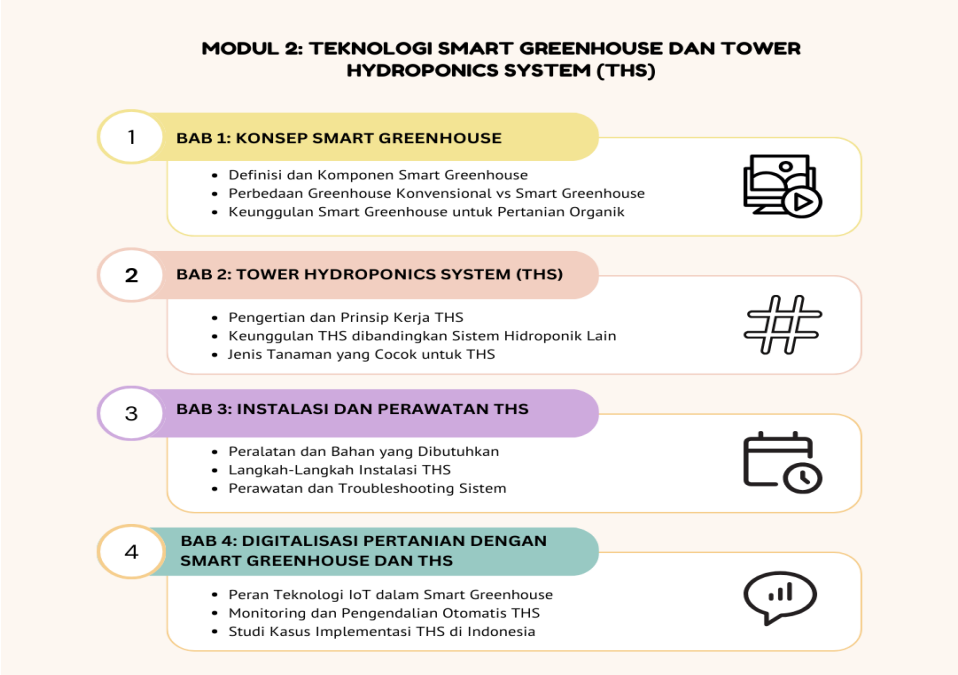

Figure 12. Module 2 about Smart Greenhouse Technology and Tower Hydroponics System (THS)

Figure 13. Module 3 about Organic Farming Production and Marketing Management

Implementation Melon Greenhouse

Figure 14. Greenhouse Construction Process

The implementation of the transformation of Village-Owned Enterprises (BUMDes) towards sustainable agro-industry is carried out through the Smart Greenhouse and Tower Hydroponics System approaches, which are applied to the organic farming cultivation process. The activity begins with the construction of Smart Greenhouse infrastructure equipped with temperature, humidity, and plant nutrition control technology. In the smart greenhouse, the cultivation process is better protected from extreme weather, pest attacks, and

diseases, so that the quality and quantity of the harvest are more guaranteed. In addition, the Tower Hydroponics System is applied to maximize the use of vertical space, making it more efficient and resource-friendly. In the implementation process, farmers are given training on hydroponic cultivation technology, maintenance procedures, nutrient management, and organic pest and disease control. The training also includes the application of organic product quality standards according to applicable regulations, packaging, and finding a wider market and greater added value.

Figure 15. Agricultural Activities in the Greenhouse

The seed sowing process begins with selecting superior and disease-free seeds, then sown in media that meets organic farming standards. Seeds that meet the requirements are then transferred to the vertical Tower Hydroponics rack, given nutrients according to the required dosage, and their growth is monitored in real-time. In the maintenance process, farmers also learn about the use of sensor technology to maintain water quality, pH, and EC (Electrical Conductivity) so that the roots can absorb nutrients more optimally. When it is time to harvest, the harvest process is also carried out according to organic quality standard procedures. The harvest is then sorted, cleaned, labeled, and ready to be marketed, thus providing added value to BUMDes, increasing community income, and encouraging the independence of an environmentally friendly, healthy, and sustainable rural economy.

Increasing Melon Greenhouse Productivity

The implementation of digital technology in melon greenhouse cultivation in Wonosari Village, Pakisaji District, shows significant results in increasing agricultural productivity. Increasing melon harvest yields in each planting cycle is a direct indicator of success. The following data shows a comparison of melon greenhouse productivity before and after the implementation of current agricultural training and digital technology:

Table. 4 Comparison of Melon Greenhouse Productivity (Land Area 100 m²)

Indicator	Before Intervention	After Intervention	Change	Increase (%)
Land Area (m²)	100	100	-	-
Number of Plants per Cycle	250	250	-	-

Average Fruit Weight per Plant (kg)	1,5	1,95	+0,45	+30%
Total Production per Cycle (kg)	375	487,5	+112,5	+30%
Selling Value per kg (Rp)	25.000	25.000	-	-
Total Income per Cycle (Rp)	9.375.000	12.187.500	+2.812.500	+30%
Production Space Efficiency (kg/m²)	0,75	0,975	+0,225	+30%
Water Usage per Cycle (liters)	1.200	960	-240	-20%
Average Harvest Time (days)	90	75	-15	-16,7%

The results showed that the use of a hydroponics tower system and an innovative greenhouse in the organic melon farming method had a significant impact on productivity. Plants cultivated in this system had a yield increase of 20–25% compared to plants grown in soil, as well as 30–50% faster growth (Mohfatteh et al., 2024). The number of plants cultivated per cycle was 50 plants on a 100-square-meter land area. However, the average fruit weight per plant increased by 0.45 kg, or 30%, from 1.5 kg to 1.95 kg. Overall production per cycle was directly affected by this increase, increasing by 22.5 kg or 30%, from the previous 75 kg to 97.5 kg. Income per cycle also increased from IDR 1,875,000 to IDR 2,437,500, representing a 30% increase of IDR 562,500. This increase in productivity indicates that the application of innovative greenhouse-based agricultural technology and vertical hydroponic systems not only increases space efficiency but also has a direct impact on crop yields and the economic Value of farmers. This supports the direction of BUMDe's transformation towards a sustainable agro-industry based on environmentally friendly technology and resource efficiency. The application of innovative greenhouse-based agricultural technology and vertical hydroponic systems not only increases space efficiency but also has a direct impact on crop yields and the economic Value of farmers (Shahab et al., 2024).

Technological interventions also help optimize resource use. Hydroponic systems offer higher yields, improved water efficiency, and sustainable production, utilizing less water and land (Rahman et al., 2024). The automatic drip irrigation system saved 20% of water per cycle, reducing the water usage from 1,200 liters to 960 liters. In addition, the harvest time was shortened from ninety days to seventy-five days, indicating an increase in time efficiency of up to 16.7%. Overall, the implementation of innovative greenhouse technology and tower hydroponics systems increased production and farmer income while also enhancing resource and time efficiency. It is crucial to realize sustainable and highly competitive melon farming at the village level.

5. CONCLUSION

The transformation of BUMDes Wonokerso Village into a sustainable agro-industry has shown positive and successful implementation results. It has been proven that Smart Greenhouse and Tower Hydroponics System (THS) technology can increase the efficiency of land use and produce more productive organic farming without relying on chemical pesticides. In addition to improving environmentally friendly agricultural practices, this technology offers new opportunities for product downstreaming and the growth of the local agro-industry sector.

BUMDes are not only economic entities; they also help local farmers learn about economics and build their businesses. Increasing the capacity of farmer employees, strengthening village institutions, and establishing an agricultural ecosystem that supports food security and village economic independence are all the results of this action. Institutional approaches, collaborative support, and contextual economic education are additional factors that contribute to the success of implementation. This activity has demonstrated that the transformation of BUMDes to be based on green technology can be achieved in a real and sustainable manner. However, there are still some obstacles, such as a lack of access to capital and low levels of technological literacy. Therefore, to promote and replicate this model in other villages, increasing managerial capacity, regulatory support, and multi-party cooperation are essential.

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