

Effectiveness of Plant Pest Control Technology on Watermelon Productivity and Quality

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ABSTRACT

This study aims to analyze the effectiveness of various technological innovations for controlling plant pests, including chemical pesticides, biopesticides, biological agents, as well as digital technology and artificial intelligence-based precision agriculture in increasing the productivity and quality of watermelon fruit. Based on the results of a systematic literature review of publications from 2018–2025, it was found that environmentally friendly approaches such as biopesticides and Integrated Pest Management systems can reduce the use of synthetic pests by up to 60%, improve soil health, and increase fruit quality in terms of size, sugar content, and shelf life. Meanwhile, the application of precision and digital technologies based on sensors and AI has been proven to increase input efficiency and the effectiveness of controlling Plant Pests while reducing production costs. Socio-economic analysis shows that the success of technology adoption is highly dependent on support from extension services, digital literacy, and the availability of technological facilities at the farmer level. Thus, the integration of technological innovations for controlling pests in an adaptive and sustainable manner is key to increasing the productivity, efficiency, and resilience of watermelon farming in various agro-ecosystems.

Keywords: Integrated Pest Management (IPM), Biopesticides, Precision Agriculture, Pest Control Technology

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INTRODUCTION

Global factors such as climate change, urban expansion, and unsustainable cultivation practices contribute to the spread of plant pests (PTOs). Climate variability alters seasonal patterns and environmental conditions, influencing the development of pests and diseases, making pest attacks more frequent or severe. Furthermore, agricultural land conversion due to urbanization narrows production space and increases pressure on farmers. The FAO (2021)

estimates that PTOs can cause yield losses of between 20% and 40% globally.

Agriculture in Indonesia plays a crucial role in national development, both for economic growth and equitable development. The agricultural subsector itself has made a significant contribution to national development. According to the Central Statistics Agency (BPS) (2023), the agricultural subsector contributed 13.57% to Gross Domestic Product (GDP) in the third quarter. This reflects the agricultural sector's second-largest contribution to GDP after the processing industry, which contributed 18.67%.

Watermelon is a leading horticultural commodity with high economic potential and growing market demand, playing a crucial role in increasing farmers' incomes and supporting the growth of the national agricultural sector. However, the sustainability of watermelon productivity and quality is significantly impacted by attacks by Plant Pest Organisms (OPTs) such as aphids, armyworms, and pathogenic fungi. These can reduce yields by reducing the number of fruits and productivity per hectare, while also reducing fruit quality by causing uneven fruit size, reduced sugar content (°Brix), and increased damage to the skin and flesh. This situation demonstrates that despite watermelon's significant potential as a leading commodity, the challenge of pest infestations can hinder optimal yields, both in terms of volume and quality.

In the field, many farmers still struggle to identify the type and extent of Pest Infestations, resulting in ineffective and ineffective treatment. This situation is exacerbated by the low adoption of effective and sustainable control technologies, as most farmers still rely on chemical pesticides to combat pest and disease attacks. Excessive pesticide use not only increases production costs but also reduces fruit quality, damages soil health, and increases the risk of pest resistance. Therefore, increasing the quantity and quality of watermelon production requires the implementation of innovative, environmentally friendly pest and disease control technologies that align with sustainable agricultural principles to maintain long-term productivity and balance the agricultural ecosystem.

According to Hossain et al. (2022), mild infection by the fungus *Fusarium oxysporum* f. sp. *niveum* on watermelon can reduce productivity by up to 15% due to impaired water and nutrient absorption by the roots. Furthermore, Nurdin et al. (2023) reported that attacks by *Trichoderma* spp. and aphids during the early growth phase cause a decrease in fruit quantity and yield quality, characterized by uneven fruit size and decreased sugar content (°Brix). The impact of plant pest attacks is not limited to yield quantity and quality but also directly impacts farmer income. Research by Suryanto & Prabowo (2023) in Central Java showed that yield losses due to pest attacks can reach 25–30% of total watermelon farming income.

Pest and disease attacks can also cause damage to crops, resulting in reduced yields. When crops are attacked by pests, the quality and quantity of produce can be reduced, thus affecting the total marketable production for farmers. Furthermore, decreased productivity directly impacts farmers' income. If yields decline, income from product sales will also decrease, potentially leading to economic hardship for farmers. In the long term, uncontrolled pest and disease attacks can trap farmers in a cycle of poverty, where they lack the resources to invest in better agricultural practices or effective pest control. Therefore, proper pest and disease management is crucial for maintaining farmer productivity and well-being.

The problems faced by watermelon farmers are not limited to pest and disease attacks, but also include the impacts of uncontrolled pesticide use. Many farmers still rely on chemical pesticides without considering the long-term impacts on the environment and health. Excessive pesticide use can lead to soil and water pollution, as well as endanger the health of farmers and consumers. This highlights the need for a more sustainable approach to pest and disease management, including the implementation of Integrated Pest Management (IPM) methods.

This article aims to analyze the effectiveness of various technological innovations for

controlling plant pests (OPT), including chemical pesticides, biopesticides, biological agents, as well as digital technology and precision farming systems, in increasing watermelon productivity and quality. Furthermore, this article also reviews the application of environmentally friendly approaches and Integrated Pest Management (IPM) systems in efforts to reduce the use of synthetic pesticides, maintain soil health, and support the sustainability of watermelon farming to remain efficient, adaptive, and competitive in various agroecosystems.

METHODS

This research employed a systematic literature review method, conducting online searches of various international scientific databases, including ProQuest, ScienceDirect, SpringerLink, and Google Scholar. The search was limited to publications from 2018 to 2025 to ensure that the information reviewed was relevant and reflected the latest developments in plant pest (Pest) control technology. Article selection was conducted based on established inclusion criteria, encompassing both empirical research and theoretical studies that specifically examine the relationship between Pest control technology and the physiological aspects, productivity, and yield quality of watermelon (*Citrullus lanatus*). Articles that were irrelevant to the research topic or not available in full-text form were excluded from the analysis process. Therefore, only literature that met the standards of scientific merit and topic suitability was used as primary sources.

The selected articles were then analyzed using a descriptive-comparative approach. Each study was reviewed based on the type and mechanism of the control technology used, whether chemical, biological, or digital, to understand its effectiveness in suppressing Pest infestations. Furthermore, the analysis focused on how each technology affects fruit quality parameters, such as sugar content (°Brix), fruit color and size, and shelf life. The synthesis phase was conducted by integrating findings from various studies to obtain a comprehensive picture of the role of technological innovation in improving watermelon productivity and quality. The findings were then compared to identify the most effective technologies, development opportunities, and implementation challenges in the context of sustainable watermelon cultivation.

RESULT AND DISCUSSION

Watermelon Pest Control Technology

Synthetic pesticides are used as a control technology for plant pests (OPT) in watermelons, developed using a chemical approach inspired by natural bioactive compounds. These synthetic pesticides are designed to be more stable than natural pesticides, thus providing long-lasting and effective pest control on a large scale. An example is pyrethroids, which are synthetic analogs of natural pyrethrins extracted from chrysanthemums. These pyrethroids improve thermal stability and photostability, allowing them to persist longer in the field, allowing for reduced application frequency. However, the use of synthetic pesticides also presents challenges such as the emergence of pest resistance and potential negative impacts on non-target organisms (Khan et al. 2025).

Research conducted by Chattha et al. (2025) showed that the application of Anaerobic Soil Disinfestation (ASD) technology using a combination of chicken manure and molasses could be an innovative and environmentally friendly method of controlling Plant Pests (OPT) in watermelon cultivation. This method creates anaerobic soil conditions that significantly suppress weed populations and soil-borne pathogens, including *Fusarium oxysporum* and *Rhizoctonia solani*, without the use of chemical pesticides. Research results show that ASD treatment not only reduces pest attack intensity by more than 80% but also increases vegetative growth, fruit weight, and yield quality of several superior watermelon genotypes,

such as 'Extazy' and 'Sangria'.

Hossain et al. (2022) demonstrated that the application of Trichoderma-based biopesticides to watermelon fields reduced Fusarium wilt disease intensity by up to 60%, increased root and stem biomass, and improved soil quality by increasing organic matter content and beneficial microbial activity. A similar finding was reported by Hamdi et al. (2018), who found that the use of Trichoderma harzianum and T. viride not only inhibited the growth of F. oxysporum and Rhizoctonia solani but also increased plant vigor and fruit quality in melon and watermelon plants. Thus, the use of Trichoderma-based biopesticides and antagonistic bacteria is a sustainable pest control technology innovation, functioning as both a plant protection agent and a growth stimulant to increase watermelon productivity and quality.

Qureshi (2018) explained that the use of silver or aluminum reflective mulch can significantly reduce attacks by aphids (*Aphis gossypii*) and fruit flies (*Bactrocera cucurbitae*) because light reflection from the mulch surface disrupts the insects' visual orientation. Furthermore, crop rotation with non-host crops such as corn or mung beans has been shown to suppress the development of soil-borne pathogens such as Fusarium oxysporum and increase soil fertility. Meanwhile, Frelief et al. (2021) emphasized that the combination of yellow traps and reflective mulch is effective in suppressing populations of sucking pests and fruit flies in watermelon crops, while simultaneously improving the microclimate around the plants.

Research conducted by Ye et al. (2025) highlighted the development of precision agriculture technology through the implementation of an intelligent pesticide prescription spraying system based on sensors, artificial intelligence (AI), and spatial data. This technology is designed to detect the intensity of pest and disease attacks in real time, then automatically adjust the dosage and spray pattern to suit the needs of the crops in the field. This approach has been proven to reduce pesticide use by 30–40% without compromising control effectiveness, while also reducing pesticide residues in crops and negative environmental impacts. For pest and disease control in watermelon (*Citrullus lanatus*), this system can be adapted to monitor pest attacks such as *Aphis gossypii* or soil-borne diseases such as Fusarium oxysporum, allowing for more precise, efficient, and sustainable control.

Ananda (2023) in his research compared three control modules: chemical methods, biopesticides, and IPM, which combines the use of color traps, biological agents, and field monitoring. The results showed that the IPM module was able to suppress pest attacks by up to 78% and increase crop yields by 22% compared to conventional methods. This IPM approach is not only effective in reducing pest pressure such as *Bactrocera cucurbitae* (fruit fly) and *Aphis gossypii*, but also maintains the sustainability of agricultural ecosystems by reducing the use of synthetic pesticides.

Impact of Technology on Watermelon Quantity

Pest control technology for watermelon plays a crucial role in increasing productivity and yield stability. Integrated Pest Management (IPM) has been shown to reduce yield losses due to pest attacks such as fruit flies, aphids, and caterpillars without reducing productivity. According to Pecenka et al. (2021) in PNAS, IPM can reduce insecticide use by up to 95% while maintaining or even increasing yields by increasing natural pollinator populations. This technology balances ecological and economic aspects, where input efficiency and minimal crop damage directly impact the volume of fruit harvested per hectare.

Furthermore, digital technology and precision agriculture contribute significantly to increased watermelon yields through real-time monitoring and more effective pest control. Musajan et al. (2024) showed that the adoption of digital technologies such as pesticide monitoring apps and automated irrigation systems in China's watermelon and melon sectors reduced pesticide use by up to 17% and increased yields by an average of 15% per growing

season. With the support of soil sensors, pest surveillance drones, and AI-based applications, farmers can make data-driven decisions regarding the timing and dosage of pest control, thus optimizing land productivity.

At the field level, the combination of biological control technology and land management innovations has also shown significant results in terms of production quantity. Research by Pradesh (2022) in India showed that the use of biofertilizers, botanical pesticides, and Integrated Crop Management (ICM) increased watermelon yields by 25–30% compared to conventional methods. In addition to suppressing pest attacks, this technology maintains soil health and improves fruit quality, increasing production quantity without compromising sustainability. Overall, the integration of pest control technology with modern agricultural innovation is key to supporting sustainable watermelon productivity increases in various tropical and subtropical regions.

The Impact of Technology on Watermelon Quality

In addition to reducing yields, pests and diseases also significantly impact the quality and economic value of agricultural products. Watermelons attacked by pests or diseases often exhibit physical defects such as holes, spots, or deformation, making them unsuitable for market use. Pathogen infections can cause changes in the color, flavor, and texture of the fruit, reducing consumer appeal and shortening the product's shelf life. This situation forces farmers to sell their crops at low prices or even face rejection from the market. In cases of widespread, severe infestations, the supply of low-quality fruit in the market increases, causing overall product prices to decline and eroding farmers' incomes, even for those whose crops are still of good quality. Furthermore, some pests act as vectors for viral diseases, such as aphids, which transmit mosaic virus to horticultural crops, the impact of which is often more severe than the direct damage caused by the infestation (Zhang et al. 2021).

The application of Pest Control Technology has a significant positive impact on watermelon fruit quality, both physically and chemically. The use of Trichoderma-based biopesticides has been shown to improve soil health and increase organic matter content, resulting in more uniform fruit size, higher sugar content (°Brix), and brighter flesh color (Hossain et al. 2022; Hamdi et al. 2018). This technology not only suppresses Fusarium wilt disease by up to 60% but also increases watermelon storability by improving the physiological quality of the plants. With more microbiologically balanced soil conditions, plant nutrient uptake is optimized, resulting in fruit with better texture and flavor.

In addition to biotechnology, the application of reflective mulch and color traps also contributes significantly to maintaining crop quality. The reflection of light from the surface of silver or aluminum mulch can disrupt the visual orientation of pests such as aphids (*Aphis gossypii*) and fruit flies (*Bactrocera cucurbitae*), thereby reducing the intensity of attacks on the fruit surface (Qureshi, 2018). This reduction in pest infestation directly impacts the quality of the watermelon rind, which becomes smoother and free of spots, and reduces deformation and damage to the fruit flesh. This technology also helps maintain soil moisture and temperature stability around the roots, resulting in increased water content and post-harvest fruit freshness.

Advances in artificial intelligence (AI)-based precision agriculture technology are further enhancing watermelon quality through an intelligent pesticide spraying system that adjusts the dosage and spray pattern based on the level of infestation in the field (Ye et al. 2025). This system can reduce pesticide residues by up to 40% without compromising pest control effectiveness, resulting in fruit that is safer to consume and meets export standards. The integration of spatial data and field sensors enables optimal plant environmental management, maintains plant physiological balance, and enhances overall fruit quality

characteristics. Therefore, the application of modern control technology not only maintains productivity but is also key to sustainably improving the quality and market value of watermelons.

Efficiency and Sustainability of Applying OPT Control Technology in Watermelon Cultivation

The implementation of efficient and sustainable pest control technologies is key to increasing watermelon productivity without increasing production costs or damaging the environment. Various studies have shown that technologies such as Integrated Pest Management (IPM), biological biopesticides, and artificial intelligence (AI)-based precision farming systems can reduce pesticide costs while maintaining agro-ecosystem health. Mao et al. (2023) reported that integrating digital systems into pest management in watermelon fields reduced pesticide costs by up to 32% and increased water efficiency by 18%. Similar results were found by Tian & Zhang (2022), where the use of automatic sensors for pest monitoring saved approximately 28% on pesticide costs and optimized farmer labor. This confirms that economic and ecological efficiency can be achieved simultaneously through the application of intelligent technology that adapts to field conditions.

Beyond cost efficiency, modern technology has also been shown to increase the effectiveness of agricultural inputs such as water and fertilizer. Chen & Huang (2021) demonstrated that the implementation of an Internet of Things (IoT)-based smart irrigation system in watermelon cultivation increased water efficiency by up to 21% without reducing yields. This technology allows for precise pesticide spraying and irrigation based on the level of pest infestation and the crop's water needs. This minimizes water and pesticide losses due to overapplication. This approach not only reduces operational costs but also reduces the potential for soil and water pollution, making the production system more environmentally friendly and supporting the principles of sustainable agriculture.

From an ecological sustainability perspective, the use of biopesticides and biological agents such as *Trichoderma* provides significant benefits for soil fertility and microbial biodiversity. Research by Ali & Karim (2022) shows that biopesticides not only reduce production costs by up to 25% but also enhance the activity of soil microbes, which play a role in the decomposition of organic matter. Rahman et al. (2024) added that consistent long-term application of IPM can increase soil microbial biomass by 35% and reduce pesticide residues by up to 60%. This demonstrates that bio-based pest control technology has a regenerative effect on the soil, maintains biological balance, and increases the resilience of agricultural systems to environmental degradation.

The efficiency and sustainability of implementing pest control technology in watermelon cultivation are not only oriented towards increased yields but also maintain a balance between economic, ecological, and social factors. Guo & Zhang (2025) asserted that integrating AI into the IPM system increased pesticide use efficiency by up to 35% and water efficiency by 22% in the tropical horticulture sector. This approach fosters the development of an intelligent, adaptive, and highly competitive agricultural system. In the future, the success of increasing watermelon productivity will be measured not only by the volume of the harvest, but also by the extent to which the technology maintains soil health, resource efficiency, and the long-term well-being of farmers.

Social Economic Analysis and Technology Adoption by Farmers

Socioeconomic analysis of agricultural technology adoption shows that farmers' decisions to adopt innovations such as IPM, biopesticides, or precision agriculture are heavily influenced by social dynamics, farming experience, and their perception of risk. Smallholder farmers are typically more cautious because adoption decisions are directly related to income stability and the potential for losses if the new technology is not suited to their land conditions

or experience. A study by Owusu & Abdulai (2019) showed that the availability of ongoing extension services and field training made farmers more confident in trying IPM because they saw direct evidence of success. Trust among farmers and access to learning resources are equally important factors as the effectiveness of the technology itself, as both influence farmers' ability to assess the long-term benefits of the innovation.

Biopesticide adoption remains relatively low, especially in areas where synthetic pesticide use is deeply ingrained. Many farmers perceive biopesticides as slower-acting, less effective against pests, and have a shorter duration of action, thus increasing the risk of crop damage. Furthermore, the lack of product availability at the local distributor level and minimal training on application reinforce this hesitation. The conceptual model developed by Abraha et al. (2021) emphasizes that farmer awareness of the environmental and long-term benefits of biocontrol is key to increasing adoption. When farmers are provided with field evidence and clear explanations of how biopesticides work, their perceptions tend to change. However, this requires intensive extension support and communication, not just product availability in the market.

In precision agriculture, the challenges faced by smallholder farmers tend to be more complex. In addition to requiring significant initial capital, this technology also requires the ability to operate digital devices and understand agronomic data. Dibbern et al. (2025) stated that the biggest obstacles in developing countries are low digital literacy and limited infrastructure, such as internet access and technical support. When farmers lack support to help interpret data or operate devices, precision technology becomes difficult to utilize optimally. Even when the benefits of input efficiency or increased yields are clear, socioeconomic unpreparedness means many smallholder farmers are only able to adopt a small portion of the technology, rather than the full system. This situation emphasizes that the success of precision agriculture is not only related to the sophistication of the equipment, but also the readiness of the support system surrounding the farmer.

Socioeconomic barriers such as limited capital, limited mentoring services, and unequal access to technology are key factors limiting the adoption of agricultural innovations by smallholder farmers. Habtewold & Heshmati (2023) emphasize that although technology can increase productivity or cost efficiency, farmers often do not experience the full benefits due to a lack of long-term guidance and an adequate supportive environment. Conversely, when farmers have access to clear information and can see evidence of success in neighboring farms, their motivation to adopt technology increases significantly. A UNDP (2021) report also highlights that policies that favor smallholder farmers, such as equipment subsidies, access to soft credit, or digital training programs, can reduce adoption disparities. Therefore, institutional support is crucial for innovation to be truly accessible to a wider audience, not just high-capacity farmers.

The socioeconomic impacts of agricultural technology adoption are generally positive, particularly in increasing household income, productivity, and food security. Habtewold & Heshmati (2023) show that adopting technology tailored to local conditions contributes significantly to improved welfare, but the impact varies depending on market access, input availability, and the quality of technical assistance. A concrete example is seen in research by Owusu & Abdulai (2019), which found that farmers who implement IPM consistently achieve higher net incomes than non-adopters, primarily due to reduced pesticide costs and a reduced risk of crop failure. However, these benefits are not achieved automatically; policy support, training, and gradual implementation are required to ensure the technology can be integrated into farmers' practices sustainably. This demonstrates that technology adoption must be viewed as a socio-economic process, not simply a technical change in cultivation.

Implications for Sustainable Farming and Food Security

Increasing watermelon productivity significantly contributes to the local economy because this commodity has a long value chain, from labor to cultivation and transportation to the retail market. Economic analysis of the watermelon sector shows that increased production volume can increase revenue turnover at the regional level and provide a multiplier effect for small businesses around production centers. At the national level, increased horticultural commodity production plays a role in strengthening the fresh food supply and improving agricultural trade performance. However, these economic benefits must be accompanied by efficient resource management to avoid excessive pressure on the environment (Dekamin et al. 2025).

From a farming sustainability perspective, increased productivity reflects not only the volume of harvests but also the responsible cultivation process. Studies examining material flows and environmental impacts in watermelon cultivation emphasize that water efficiency, appropriate fertilizer dosages, and organic fertilizer practices play a crucial role in maintaining soil health and reducing the ecological footprint (Dekamin et al. 2025). This approach aligns with the FAO framework, which emphasizes that increased production must be accompanied by sustainable cultivation practices to prevent long-term land degradation (FAO, 2021). Therefore, increasing watermelon yields can be a foundation for sustainability if implemented through agroecosystem-friendly practices.

The relevance of increasing watermelon productivity to SDG 2 (Zero Hunger) is evident when higher production increases the availability of fresh food while strengthening the economic access of farming households. UNIDO & FAO (2024) emphasize that increasing farmer incomes through horticultural commodities can reduce food insecurity and improve the quality of community consumption, especially in rural areas. Furthermore, the link with SDG 12 (Responsible Consumption and Production) arises because the watermelon supply chain is vulnerable to post-harvest losses, so increased production must be accompanied by reduced food loss through improved storage, transportation, and harvest handling (FAO, 2023). Therefore, increased productivity will only be sustainable if accompanied by efficient supply management and minimal waste.

The potential for replicating watermelon cultivation technology to other horticultural commodities is significant because most of the technologies used, such as precision irrigation, soil moisture sensors, and image-based growth monitoring, are cross-commodity. Reviews of the application of precision agriculture in horticulture indicate that the technology is relatively easy to adapt to crops such as melons, chilies, or tomatoes, provided that input doses and cultivation protocols are adjusted (Tiwari, 2019). Other research testing the use of precision systems on watermelons also confirms that the technology can improve water efficiency and increase yields, thus opening up opportunities for application to similar economically valuable crops (Zeleny et al., 2024). Thus, the successful adoption of this technology in watermelons could serve as a model for other horticultural commodities facing similar challenges in productivity and sustainability.

CONCLUSION

This study shows that the application of various technological innovations for controlling plant pests (OPT), such as biopesticides, biological agents, digital technology, and precision agriculture systems, has been proven to significantly increase watermelon productivity and quality while reducing dependence on synthetic pesticides. Environmentally friendly approaches such as Integrated Pest Management (IPM) and biotechnology play a crucial role in maintaining soil health, suppressing pest infestations, and improving fruit quality from a physical and chemical perspective. The integration of sensor-based technology and artificial intelligence also contributes to increasing the efficiency of agricultural input use, lowering production costs, and supporting the sustainability of watermelon farming in various

agro-ecosystems. However, the success rate of technology adoption is strongly influenced by socioeconomic factors such as access to information, extension support, and farmer readiness to embrace innovation.

To increase the effectiveness of implementing OPT control technology in watermelon cultivation, institutional and policy support is needed that strengthens farmers' access to training, technical assistance, and affordable financing. The government and agricultural institutions are advised to expand evidence-based extension programs in the field to better understand the long-term benefits of implementing IPM systems and precision technology. Furthermore, collaboration between researchers, agricultural industry players, and farmers needs to be strengthened to accelerate technology transfer tailored to local conditions. This effort will not only increase the efficiency and productivity of watermelon farming, but also strengthen food security and the sustainability of the agricultural system in the future.

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