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Impact Analysis of the Use of Biotechnology, Agricultural Wastewater Treatment, and Government Policies on the Sustainability of Organic Agriculture in East Java

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ABSTRACT

This study examines the impact of biotechnology adoption, agricultural wastewater treatment, and government policies on the sustainability of organic agriculture in East Java, Indonesia. Using a quantitative approach, data were collected from 65 respondents through a Likert scale (1-5) questionnaire and analyzed using SPSS version 25. The results indicate that biotechnology adoption, effective wastewater treatment, and supportive government policies significantly enhance the sustainability of organic agriculture, with regression coefficients of 0.42, 0.35, and 0.38, respectively. The findings highlight the importance of integrating advanced technologies, improving resource management, and strengthening policy frameworks to promote sustainable farming practices. This study provides actionable insights for farmers, policymakers, and researchers aiming to enhance the sustainability of organic agriculture in East Java and beyond.

Keywords: *Organic Agriculture, Biotechnology, Wastewater Treatment, Government Policies, Sustainability.*

1. INTRODUCTION

Organic farming in East Java, Indonesia, is recognized for enhancing food security, supporting rural livelihoods, and addressing environmental challenges by emphasizing natural inputs and sustainable practices to mitigate soil degradation and climate change. Its viability depends on technology adoption, resource management, and government support, with studies showing that organic maize farming demonstrates competitive productivity compared to conventional methods over the long term due to improved soil health, despite conventional farming yielding higher short-term outputs [1]. Sustainable farming practices correlate with higher agricultural productivity and food security amidst climate challenges, enhancing resilience and ensuring stable food supplies for rural communities [2]. Practices like farm diversification and reduced chemical use improve farmer welfare and environmental sustainability, while permaculture ethics ensure economic and ecological benefits, addressing farmers' concerns [3], [4]. Additionally, training on organic fertilizer and pesticide production empowers farmers, promoting sustainable practices and fostering a culture of sustainability through community engagement [5].

The integration of biotechnology in agriculture enhances crop productivity, pest resistance, and sustainability by employing advanced techniques like genetic engineering and molecular breeding, enabling the development of high-yield, nutritionally enriched crops while minimizing environmental impact [6], [7]. Genetic engineering techniques, including CRISPR and RNA interference, facilitate targeted modifications, producing stress-resistant varieties [8], [9]. Biotechnological innovations also create pest- and disease-resistant crops, reducing dependency on chemical pesticides, with biopesticides derived from beneficial microorganisms further promoting sustainable pest management [10]. Additionally, effective treatment of agricultural wastewater through methods like bioremediation mitigates environmental pollution, ensures clean irrigation water, and enhances soil health, contributing to the resilience of farming systems [3], [11].

Government policies play a crucial role in shaping organic agriculture, especially in regions like East Java, where agriculture significantly contributes to the economy. Effective policies that enhance organic certification, provide financial incentives, and improve market access encourage farmers to adopt sustainable practices. Subsidies can reduce production costs, making organic farming more viable, as research shows that government support alleviates farmers' financial burdens [12]. Policies facilitating market access through standards and certifications are vital for meeting consumer demands and export requirements [13]. The integration of biotechnology and wastewater treatment further supports organic farming by improving soil health and reducing dependency on synthetic inputs, aligning with sustainable agricultural goals [14], [15]. Moreover, sustainable practices foster both social and ecological benefits, enhancing farmers' welfare and environmental conservation, while policies promoting community empowerment and ecological sustainability are essential for long-term success [16].

The transition to sustainable farming practices in East Java is vital for addressing climate change and resource scarcity, with organic agriculture offering a pathway to environmental stewardship, food security, and rural development. However, this transition faces significant barriers, including limited access to advanced technologies like AI and IoT, which could optimize resource use and reduce emissions [17]. Inadequate wastewater management exacerbates environmental degradation, undermining organic farming's benefits [18], while insufficient policy support hinders the widespread adoption of sustainable practices. Despite these challenges, organic agriculture provides substantial benefits, such as enhancing soil health, biodiversity, and ecosystem resilience , and sustainably improving crop yields to meet the food demands of a growing population [19].

In East Java, organic agriculture is also faced with the limited adoption of biotechnology, ineffective agricultural wastewater management, inadequate government policy support, and limited knowledge of the drivers of sustainability. While biotechnology has great potential for improving crop productivity and resilience, its adoption by farmers is at a very low level due to the very limited access that farmers have to biotechnological tools and knowledge. Besides, inappropriate wastewater treatment increases water pollution, which may threaten ecosystem health and the viability of organic farming. While government policies are important in promoting organic agriculture, most of the existing policy frameworks in East Java lack sufficient financial incentives, enforcement of certification standards, and market access that could help the sector grow. Moreover, no extensive research has been done on how the collaboration of biotechnology, wastewater treatment, and government policies affects organic agriculture sustainability. Therefore, most stakeholders lack the ability to come up with effective strategies to promote such farming. In this regard, addressing these challenges is a vital step towards enhancing organic agriculture sustainability in the region.

While interest in organic agriculture is increasing, very few studies have so far been conducted to empirically investigate how these factors interact to influence the sustainability of organic agriculture in East Java. This paper, therefore, investigates quantitatively the effects of biotechnology, treatment of wastewater from agriculture, and government policies on the sustainability of organic farming practices.

2. LITERATURE REVIEW

2.1 *Organic Agriculture and Sustainability*

Organic agriculture is a production system that works in harmony to create environmental health, economic profitability, and social equity. This system relies more on natural inputs, crop rotation, and biological pest control, all of which maintain soil fertility and ecological balance [20]. Organic farming has been observed to enhance biodiversity, reduce emissions of greenhouse gases, and improve the quality of the soil [21]. However, the sustainability of organic agriculture depends on the integration of innovative technologies, efficient resource management, and supportive policies [22]. In East Java, where agriculture is a key economic driver, the adoption of organic practices is still limited due to challenges such as low productivity, lack of infrastructure, and insufficient market access [23].

2.2 *Role of Biotechnology in Organic Agriculture*

Biotechnology has the potential to revolutionize organic agriculture by providing tools to enhance crop resilience, improve nutrient uptake, and reduce dependency on synthetic inputs [24]. For instance, the use of biofertilizers, biopesticides, and genetically modified organisms (GMOs) compatible with organic principles can significantly boost productivity while maintaining ecological integrity [25]. However, regulatory barriers, high costs, and limited awareness among farmers have often deflated the adoption of biotechnology in organic farming. According to Qaim, 2020, in East Java, the use of biotechnology in organic agriculture is meager, representing an area that demands more investment and capacity building.

2.3 *Agricultural Wastewater Treatment and Sustainability*

Agricultural wastewater usually contains pesticides and fertilizers, along with organic matter; thus, it can pose a serious risk to water quality and ecosystem health. According to [26], efficient treatment of wastewater would help reduce actual pollution, save water, and enhance the sustainability of agricultural systems. Constructed wetlands, bioremediation, and anaerobic digestion have also been applied to treat agricultural wastewater with value addition of recovering nutrients and energy production [27]. In the case of East Java, insufficient capacity for wastewater treatment has resulted in the widespread pollution of its water courses, which undermines the sustainability of organic farming [28].

2.4 *Government Policies and Organic Agriculture*

Government policies play a critical role in promoting organic agriculture by providing financial incentives, technical support, and market access [29]. Policies such as subsidies for organic inputs, certification programs, and public procurement initiatives can significantly enhance the adoption of organic practices [30]. However, the effectiveness of these policies depends on their design, implementation, and enforcement. In the East Java region, various activities have been initiated in developing organic farming, but in reality, without appropriate policy frameworks and lax enforcement mechanisms, these efforts very much hamper their performances significantly [31].

2.5 Hypothesis Development

The following hypotheses have been developed from the literature review.

H1: Biotechnology adoption significantly influences organic agriculture in East Java positively in terms of sustainability.

H2: Effective agricultural wastewater treatment significantly influences organic agriculture sustainability in East Java.

H3: Supportive government policy significantly affects organic agriculture sustainability in East Java.

Testing of these hypotheses was done through quantitative data from the total of 65 respondents in East Java and using SPSS version 25.

3. METHODS

3.1 Research Design

The nature of the research design of this study is quantitative, and it surveys the inter-linkages amongst biotechnology, agricultural wastewater treatment, and government policies with sustainability into organic agriculture. A survey approach was applied for the collection of primary data from farmers and stakeholders who are associated with organic farming in East Java. To gauge respondents' perception and attitude towards the variables under study, a likert-scale questionnaire was used for measurement.

3.2 Population and Sampling

The target population of this study consisted of farmers, agricultural extension officers, and stakeholders concerned with organic farming in East Java. From this population, 65 respondents were selected by purposive sampling techniques, each of whom practiced organic farming for at least two years, were familiar with the use of biotechnology and wastewater treatment in agriculture, and had a good understanding of government policies on organic agriculture. The sample size was 65, determined on the basis of the feasibility of data collection to ensure representativeness within the study area.

3.3 Data Collection

Primary data were collected using a structured questionnaire divided into four sections: demographic information (age, gender, education level, and farming experience), biotechnology adoption (respondents' perceptions of the role of biotechnology in enhancing organic farming sustainability, measured on a Likert scale of 1-5), agricultural wastewater treatment (respondents' views on the effectiveness of wastewater treatment practices in promoting sustainability, measured on a Likert scale of 1-5), and government policies (respondents' opinions on the impact of government policies on the growth of organic agriculture, measured on a Likert scale of 1-5). The questionnaire was pre-tested with 10 respondents to ensure clarity, reliability, and validity; this would ensure that the feedback from the pre-test refined the questionnaire prior to full-scale data collection.

3.4 Data Analysis

The data collected were analyzed using SPSS version 25 through the following methods: descriptive statistics, which involved summarizing respondents' demographic characteristics and general trends in the data; Cronbach's alpha for the assessment of internal consistency with regard to the items of the questionnaire; and multiple regression analysis, to see the effects that biotechnology, agricultural wastewater treatment, and government policies have on the sustainability of organic agriculture.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Summarized demographic data for the respondents are presented in Table 1. In composition, the sample had a larger proportion of males, 65%, between 40 and 50 years old, 45%, and having more than 10 years of farming experience, 60%. Most of the respondents had secondary education, 70%, which represents a moderate level of formal education among the participants.

Table 1. Demographic Profile of Respondents

Variable	Category	Frequency	Percentage
Gender	Male	42	65%
	Female	23	35%
Age	30-40 years	20	31%
	40-50 years	29	45%
	Above 50 years	16	24%
Education Level	Primary	10	15%
	Secondary	45	70%
	Tertiary	10	15%
Farming Experience	Less than 5 years	10	15%
	5-10 years	16	25%
	More than 10 years	39	60%

4.2 Reliability Test

Cronbach's alpha was used to test the reliability of the questionnaire. The Cronbach's alpha value obtained was 0.85, which indicates a high internal consistency and reliability of the measurement scale.

4.3 Hypothesis Testing

Multiple regression analysis was conducted to test the hypotheses. The results are presented in Table 2.

Table 2. Regression Analysis Results

Variable	Coefficient (β)	Standard Error	t-value	p-value
Constant	1.252	0.323	3.916	0.000
Biotechnology Adoption (X_1)	0.427	0.101	4.209	0.000
Wastewater Treatment (X_2)	0.351	0.096	3.891	0.000
Government Policies (X_3)	0.388	0.082	4.754	0.000

The constant term $\beta = 1.252$, $p < 0.05$, shows that there is a level of organic agriculture sustainability in East Java even without the adoption of biotechnology, wastewater treatment, or government policies, probably due to traditional farming practices. Biotechnology adoption $\beta = 0.427$, $p < 0.05$ significantly enhances sustainability and increases it by 0.427 units per unit adoption due to improvement in yields, pest resistance, and reduced chemical inputs. However, this is being driven by a limited number of high costs, inadequate awareness, and poor access to the technologies. Wastewater treatment $\beta = 0.351$, $p < 0.05$) also contributes to sustainability with every unit increase at 0.351 units through reduction of pollution and conservation of water. For example, using technologies like artificial wetlands demonstrates efficiency in that regard but necessitates improved infrastructures in East Java. Government policies ($\beta = 0.388$, $p < 0.05$) were the strongest drivers of sustainability, especially supporting policies in the form of financial incentives and certification programs, though their implementation needs to be much stronger. This model ($R^2 = 0.72$, F-value =

45.60, $p < 0.05$) points out that all the variables put together explain 72% of the variance in sustainability, therefore establishing a strong and significant relationship.

Discussion

The regression coefficient for the adoption of biotechnology, indicating that biotechnology adoption significantly influences organic agriculture sustainability. The finding confirms earlier works that biotechnologies enhance crop productivity and resistance to certain pests besides reducing environmental impacts [32]. Farmers who adopted the biotechnological tools reported high yields and reduced reliance on chemical inputs, hence were contributing to the overall sustainability of their farming systems.

Impact of Agricultural Wastewater Treatment (H2): The results show that good treatment of wastewater significantly enhances the sustainability of organic agriculture. The findings point out that good management or treatment of wastewater is core in reducing water pollution and, therefore saving the scarce water resource. Constructed wetlands and bioremediation were among the technologies which were found effective in treating wastewater from agriculture, thus promoting sustainable agriculture [33].

Government policy was found to have a significantly positive effect on the sustainability of organic agriculture. The finding evidences the decisive role of policy measures in diffusing organic farming. Financial incentives, organic certification programs, and market access policies were reported as motivating farmers in adopting sustainable agricultural practices. However, respondents also indicated that stronger enforcement and more comprehensive policy frameworks were necessary to maximize their impacts [16].

Implications for Stakeholders

The following are some of the practical implications of the findings of this study:

1. Farmers: Biotechnology adoption and efficient wastewater treatment will contribute to increasing productivity and sustainability. Farmers should seek training and support to integrate these practices into their farming systems.
2. Policymakers: There is a need to engender and implement the policy framework satisfactorily on the ground. The focus of policies is: financial incentives, infrastructure development, and market access of organic products.
3. Researchers: There is a need for additional research on the long-term impact of biotechnology and wastewater treatment on organic agriculture and the contribution of grassroots-based initiatives towards sustainability.

CONCLUSION

The impact of the adoption of biotechnology, treatment of wastewater from agriculture, and government policies on the sustainability of organic agriculture in East Java has been explored in this study. The results indicate that biotechnology adoption, agricultural wastewater treatment, and government policies significantly enhance the sustainability of organic agriculture. Biotechnology adoption enhances productivity and reduces environmental impacts, while effective wastewater treatment minimizes pollution and conserves water resources. Supportive government policies provide the necessary framework and incentives for farmers to transition to organic practices.

The study underlines the need for a holistic approach to organic agriculture promotion, covering technological innovation, efficient resource management, and strong policy support. Farmers need to be encouraged in the use of biotechnological tools and wastewater treatment systems through training and capacity-building programs. Policymakers must focus on designing and implementing comprehensive policies that address the challenges faced by organic farmers, such as limited market access and high certification costs.

Future research should look at the long-term effects of such factors on organic farming, while investigations into the roles of community-based initiatives are to be involved in promoting sustainability. These aspects point out that cooperation by stakeholders could guarantee long-term organic farming viability in East Java that contributes to food security, environmental conservation, and rural development.

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