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Empowering Village Women through Circular Economy: Transformation of Organic Waste into Eco-friendly Biopesticide in Ulak Segelung Village

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ABSTRACT

This research aims to empower village women in Ulak Segelung Village through a circular economy approach by transforming organic waste into environmentally friendly biopesticides. Local communities face the dual challenges of high levels of unmanaged household organic waste, farmers' dependence on synthetic chemical pesticides, and women's low economic independence. Using a participatory empowerment model, the program involved 30 homemakers in hands-on training of EM Bokashi anaerobic fermentation technology. The program's effectiveness was evaluated using a One-Group Pretest-Posttest design. The results showed significant improvements in participants' capacity; technical knowledge increased from 48% to 86%, and practical skills rose from 40% to 82%. Environmentally, the initiative increased organic waste collection by 175% (from 8 kg to 22 kg/week). The biopesticide produced (25 liters/week) showed 55% efficacy in reducing pest intensity in local farmlands. Economically, the establishment of the Women's Business Group successfully commercialized the product with 87.5% sales growth in the second month. The study concluded that the program succeeded in creating a circular economy model that reduces environmental pollution while providing a new independent source of income for village women. The study recommended standardizing product legality and expanding market networks.

Contribution to Sustainable Development Goals (SDGs):

SDG 1: No Poverty

SDG 5: Gender Equality

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Ulak Segelung Village, Ogan Ilir Regency, is an agricultural area with high agricultural potential but faces environmental challenges, including large volumes of organic waste from household and agricultural activities. Organic waste such as onion skins, soursop leaves, lemongrass stems, rice washing water, and vegetable scraps is estimated to reach 1 to 1.5 kg per household per day, with the total potential for village waste exceeding 1 ton

per month. So far, the waste is generally disposed of without further processing, leading to environmental pollution. In the agricultural sector, village farmers remain highly dependent on chemical pesticides, which are increasingly expensive and risk damaging environmental health and soil fertility in the long run.

From the socio-economic dimension, the development of village potential is hampered by the lack of involvement of women's groups in productive economic activities. Data shows that 43% of homemakers in Ulak Segelung Village do not have independent incomes. In fact, within rural communities, women are key actors in household management and have great potential to become drivers of the circular economy if given access to



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microscale waste-treatment technology. Therefore, a strategic intervention is needed to address the problem of organic waste accumulation while opening new business opportunities for women's groups that are less financially productive.

1.2. Literature Review

Biopesticides are natural pest control agents synthesized from plant metabolites or organic waste bioconversion processes [1], [2]. In the literature, various types of bio-waste are known to contain phytochemicals that act as bioactive agents [3]. For example, papaya and soursop leaves contain antifungal and insecticidal compounds, while onion waste is rich in antibacterial compounds [4], [5]. The processing of this organic waste can be optimized through anaerobic fermentation technology using a consortium of microorganisms such as EM (Effective Microorganisms) Bokashi [6], [7]. During the fermentation process, microbes degrade the complex compound cellulose into organic acids and secondary metabolites that not only suppress pathogen growth but also extend the shelf life of the liquid biopesticide [8], [9], [10].

This model of transforming waste into biopesticides has the characteristics of an appropriate technology, ideal for adoption as an instrument of women's empowerment [11]. The process is household-scale, requires low initial capital, draws on local wisdom and materials, and can be done collectively without disrupting homemakers' main duties.

1.3. Research Objective

This study aims to analyze the effectiveness of a hands-on training program in improving the cognitive capacity and psychomotor skills of rural women in producing local biopesticides. Furthermore, this study evaluates the economic performance of the Women's Business Group (WBG), established to accelerate the downstreaming and commercialization of biopesticide products at the village level.

2. MATERIALS AND METHODS

2.1. Location and Time of Research

This service and research activity was carried out in Ulak Segelung Village, Indralaya District, Ogan Ilir Regency, South Sumatra. This village was chosen because it is an agricultural area with abundant organic waste potential, but has not been optimally utilized. The entire series of activities, from socialisation to impact evaluation, took place during the 2025-2026 academic year.

2.2. Program Target and Community Participation

The target audience for this program was women's groups in Ulak Segelung Village, including homemakers, PKK members, and women of productive age. A total of 30 participants were actively selected to participate in the entire series of training and production assistance. The approach used is a participatory empowerment model, in which the community is the primary subject in program planning and implementation.

2.3. Tools and Materials

The main raw materials used in the production of biopesticides are local organic waste, including lemongrass (22 g), soursop leaves (10 g), onion and garlic skins (70 g), chili stalks (18 g), and orange peels (25 g). Fermentation support materials include rice washing water (900 mL), agricultural EM4 microbial starter (17 mL), and carbon source in the form of brown sugar or molasses (100 g). The equipment used included digital scales, a filtering device, and a simple anaerobic fermenter unit modified from a used gallon with a capacity of 19 liters equipped with a leachate system.

2.4. Implementation Procedure

The activity implementation method is divided into four main stages:

- Socialization and Mapping:** Introduction of the program to village officials and identification of household organic waste availability.
- Technical Training (Hands-on Training):** Participants are directly trained on waste treatment techniques using the Japanese EM Bokashi fermentation method, including the assembly of a self-contained fermenter.
- Production Assistance:** Regular monitoring during fermentation to ensure the quality of the biopesticide solution.
- Application and Institutionalization Test:** Product effectiveness testing on community farms and establishment of a Women's Business Group (WBG) for sustainable business management.

2.5. Evaluation Method and Data Analysis

The program's effectiveness was measured using a One-Group Pretest-Posttest design. Data on knowledge and skills were collected through questionnaires administered before and after the training intervention. In addition, economic impact was measured through WBG sales records, while environmental impact was analyzed based on the volume of organic waste collected by the community during the program. The efficacy of the biopesticide was tested by observing pest attack intensity in a 0.5-hectare vegetable field owned by a village farmer group.

3. RESULT AND DISCUSSION

3.1. Effectiveness of Training and Capacity Building for Women

The transformation program of organic waste into biopesticides began with socialization and hands-on training. Program effectiveness was evaluated by comparing technical understanding before (pre-test) and after (post-test) training among 30 female respondents. The evaluation results showed significant improvements in both cognitive knowledge and psychomotor skills (Figure 1).

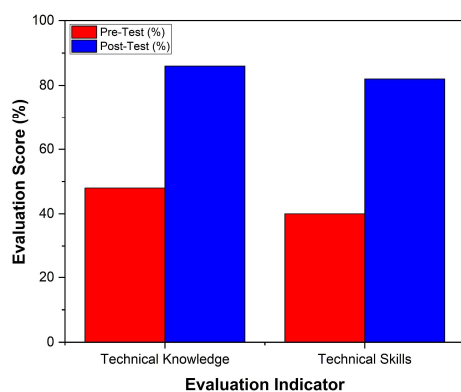


Fig. 1. Comparison of participants' technical knowledge and practical skills before and after the training program.

Figure 1 compares participants' levels of technical knowledge and practical skills before and after the biopesticide production training program. The results indicate a significant improvement in both areas, particularly in understanding the selection of raw materials, the fermentation process, product formulation, and field application techniques for biopesticides. Before the training, most participants still had limited knowledge of using organic waste as a biopesticide. However, after the training, participants demonstrated improved practical skills in independently producing biopesticides, including operating simple fermenters and controlling product quality. These findings indicate that the training program not only enhanced technical capacity but also strengthened the group's readiness to develop community-based biopesticide enterprises.

The 82% increase in practical skills demonstrates that the demonstration-and-hands-on-mentoring method is highly effective in rural communities. The use of real demonstration media (such as a 19 L modified fermentation equipment unit) made it easier for homemakers to replicate the process independently at home.

A fermentation system using modified 19 L containers is still sufficient for initial production, but with an 87.5% increase in demand, the production capacity of 25 liters per week becomes inadequate. The estimated new requirement could reach 45–50 liters per week. To meet this demand, WBG can increase the number of fermenter units to 3–4, operated in rotation to ensure continuous production. Another alternative is to use larger-capacity fermentation tanks (100–200 liters) to improve efficiency and standardize quality, although this requires a higher investment. In the early stages, adding more gallon units is more realistic before transitioning to a semi-industrial scale.

The enthusiasm and active involvement of the participants during the anaerobic fermentation training are documented in Figure 2.



Fig. 2. Participants engaging in hands-on training for processing organic waste into biopesticides.

The success of this capacity-building aligns with experiential learning theory, in which rural women's groups more readily absorb appropriate technological innovations when they are directly involved in practice. The selection of a simple anaerobic fermentation method using modified used gallons reduced participants' psychological barriers to adopting new technology. This shows that the key to technology dissemination at the village level is not the sophistication of the equipment, but the ease of replication and availability of cheap local materials.

3.2. Waste Transformation and Biopesticide Characterization

Active community participation is evident in the surge in household-level organic waste collection. Before the program was implemented, the managed kitchen and garden waste was only about 8 kg/week; after the program, it rose sharply to 22 kg/week, an increase of 175%. All organic waste is processed using appropriate EM Bokashi fermentation methods. Before the fermentation process begins, organic waste is weighed and divided into two treatment variants based on differences in carbon source: brown sugar (Formulation A) and molasses (Formulation B). Details of the raw material composition and starter usage ratios for the two formulations are presented in Table 1.

During the production assistance period, routine monitoring of changes in the physical and sensory characteristics of the two formulations was conducted during the 7-day anaerobic fermentation period. This monitoring aims to ensure that the bioconversion process runs optimally. The results of daily observations regarding changes in color, aroma, and physical condition of the products are presented in Table 2.

Daily monitoring of fermentation dynamics revealed differences in organic matter breakdown activity, influenced by the carbon source. In Formulation A (brown sugar), the peak of lactic acid bacteria activity was observed on day 5, characterized by the formation of large amounts of foam, an indication of CO₂ gas release during the anaerobic carbohydrate breakdown process [12], [13]. The use of brown sugar provides a purer source of sucrose for the bacteria in the EM consortium, thereby triggering a faster decrease in pH and producing metabolites, such in organic acids, that impart a fresh aroma typical of fermentation [14], [15]. In contrast, in Formulation B, a musty aroma began to dominate from day 4, indicating that the volatile compound profile of

molasses tends to mask the fresh aroma of bioactive organic matter extracts [16], [17].

Table 1. Raw Material Composition and Formulation of Biopesticide Preparation

Raw Material Component	Main Function	Formulation A	Formulation B
Rice Washing Water	Solvent or Organic fermentation medium	900 mL	900 mL
Lemongrass	Bioactive compound (<i>citronellal</i>)	22 g	22 g
Soursop Leaf	Bioactive compound (<i>annonacin</i>)	10 g	10 g
Red & White Onion	Antibacterial agent (<i>flavonoid/sulfur</i>)	70 g	70 g
Chili Stalk	Natural pest repellent	18 g	18 g
Orange Peel	Fragrance enhancer & repellent	25 g	25 g
Brown Sugar	Pure carbon source	100 g	-
Molasses	Carbon source	-	100 g
EM4 (Agriculture)	Microbial consortium starter	17 mL	17 mL

The final results showed that the use of brown sugar resulted in a product with more stable sensory characteristics. The physical appearance of the final bottled biopesticide, which is ready for application, is shown in Figure 3. The women's group's average production capacity was 25 litres per week. Based on field trials, this biopesticide has been proven to reduce pest intensity by 55%. This efficacy is strongly influenced by the phytochemical profiles of the raw materials, such as annonacin compounds from soursop leaves, citronellal from lemongrass, and flavonoids and sulfur from onion skins, which are optimally released into the media during fermentation [18]. Although its effectiveness is slightly lower than that of chemical pesticides (60-65%), this biopesticide is considered much safer and more environmentally friendly, leaving no toxic residues in the soil.

activity, improving soil structure, and reducing the risk of pest resistance, a common issue resulting from the continuous use of chemical pesticides. Therefore, although their control efficacy is slightly lower, the resulting economic, ecological, and health benefits make biopesticides a more sustainable and viable alternative, particularly for smallholder farmers and organic farming systems.

Table 2. Dynamics of Changes in Physical and Sensory Characteristics During the Fermentation Process (Days 1-7)

Day-	Formulation A (Carbon Source: Brown Sugar)	Formulation B (Carbon Source: Molasses)
1	Color: Brownish; Fresh.	Color: Blackish brown; Aroma: Fresh, predominantly molasses odor.
2	Color: Brownish; Fresh, typical of fermentation.	Color: Blackish brown; Aroma: Fresh, typical of vegetables.
3	Color: Brownish; Fresh onion smell; Physical: Pulp and liquid start to separate.	Color: Blackish brown; Aroma: Fresh vegetable odor.
4	Color: Light brown; Aroma: Pungent, acidic; Physical: Precipitate formed.	Color: Blackish brown; Aroma: Starts to smell musty.
5	Color: Light brown; Aroma: Pungent; Physical: Lots of foam and sediment appear.	Color: Blackish brown; Aroma: A musty odor predominates.
6	Color: Light brown; Aroma: Pungent; Physical: Decreased foam; clear sediment.	Color: Blackish brown; Aroma: Musty odor; Physical: Degraded precipitate.
7	Color: Clear light brown; Aroma: Fresh, typical of fermented biopesticides.	Color: Dark blackish brown; Aroma: Tends to be musty.



Fig. 3. Visual observation of the biopesticide fermentation process: (a) Comparison of the final liquid characteristics between Formulation A and Formulation B on day 7, and (b) Active fermentation phase indicated by foam formation in Formulation A on day 5.

sAlthough the effectiveness of biopesticides in reducing pest populations by 55% is still slightly lower than that of synthetic chemical pesticides, which generally achieve 60–65%, this difference can be considered a reasonable compromise in the context of sustainable agriculture. Biopesticides based on organic waste have significantly lower production costs because they utilize readily available local raw materials, thereby reducing farmers' dependence on expensive external inputs. Additionally, the use of biopesticides does not leave toxic residues in soil, water, or crops, making them safer for farmers and consumers. In the long term, the application of biopesticides also contributes to improved soil quality by maintaining beneficial microbial

Economic Impact and Circular Economy Implementation

The culmination of this empowerment program is the formation of a Women's Business Group (WBG), which serves as the driving force for the commercialization of local biopesticide products. The group's economic performance in the first two months post-training was measured through sales volume and revenue generation (Figure 4).

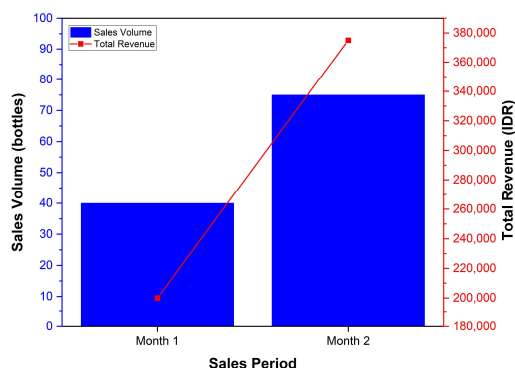


Fig. 4. Economic performance of the Women's Business Group (sales volume and total revenue) during the first two months.

Sales growth of 87.5% in the second month indicates strong market acceptance, particularly among local farmer groups that are beginning to switch to organic farming practices. The transformation of waste (zero economic value) into a bottled biopesticide worth IDR 5,000/250 mL created significant added value. This proves that the circular economy strategy not only solves the problem of household waste pollution but also successfully provides new financial independence for unproductive women's groups in Ulak Segelung Village.

Furthermore, this initiative directly contributes to achieving the Sustainable Development Goals (SDGs), specifically SDG 5 (Gender Equality) and SDG 12 (Responsible Consumption and Production). Financially, the Women's Business Group (WBG) succeeded in shifting the household economic structure from a linear (buy-use-dispose) to a circular model. The profit margins from the sale of local biopesticides not only provide economic incentives but also increase women's bargaining power in family economic decision-making.

In the future, the standardization and legal status of biopesticide products must be prioritized so that these products can be marketed more widely and sustainably. In addition to business permits such as PIRT for packaging and distribution, biopesticides also require official registration as biological pesticides through the Ministry of Agriculture of the Republic of

Indonesia, specifically with the Directorate General of Agricultural Infrastructure and Facilities and the Pesticide Commission. Key requirements include identity testing against target organisms, toxicity testing, product stability, and safety for humans and the environment. Additionally, a product label compliant with standards, application dosage information, and product shelf life are required. With this legal status, biopesticide products from the Women's Business Group (WBG) not only command a higher market value but also gain stronger market trust and opportunities to enter organic farming programs as well as local government procurement initiatives. y of the active ingredient, production processes, efficacy Additionally, a product label compliant with standards, application dosage information, and product shelf life are required. With this legal status, biopesticide products from the Women's Business Group (WBG) not only command a higher market value but also gain greater market trust and opportunities to enter organic farming programs and local government procurement initiatives.

4. CONCLUSION

The community empowerment program, which transforms organic waste into biopesticides in Ulak Segelung Village, has proven effective in increasing human resource capacity while providing environmental and economic solutions. The hands-on training approach and the use of appropriate, easy-to-replicate technology are key to significantly improving the knowledge and technical skills of village women's groups.

The EM Bokashi fermentation method, combined with local bioactive ingredients, has been proven to produce biopesticides that effectively suppress pest populations, are safe for soil ecosystems, and can significantly reduce the volume of household organic waste. In addition, the formation of the Women's Business Group (WBG) has successfully initiated a circular economy model at the rural level, transforming previously valueless waste into commercial products that provide a new source of independent income. The success of this program directly supports the Sustainable Development Goals (SDGs) agenda in the sectors of poverty alleviation, gender equality, sustainable production, and preservation of terrestrial ecosystems. To sustain the program, support is needed to strengthen product legality and quality standards, and to expand marketing networks so that this local biopesticide can be adopted on a wider scale across agribusiness.

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