Contents lists available at openscie.com
E-ISSN: 2829-4521
Indonesian Journal of Community Services Cel
DOI: 10.70110/ijcsc.v4i3.116
Journal homepage: https://ijcomcel.org

Optimization of Organic Waste Management in Garahan Village Through EM4 Application: Evaluation of Its Effectiveness in Producing Compost

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ARTICLE INFO

Article History:
Received 2 November 2025
Revised 20 December 2025
Accepted 22 December 2025
Published 24 December 2025

Keywords:
Community service,
Farmers empowerment,
Liquid organic fertilizer,
Waste utilization.

ABSTRACT

Background: Organic waste management in rural areas remains a significant challenge, where household and agricultural waste accounts for approximately 65% of total waste volume, contributing to environmental degradation and increasing greenhouse gas emissions.
Aims: This Community Service Program aimed to evaluate the effectiveness of Effective Microorganisms 4 (EM4) in converting organic waste into compost in Garahan Village, Silo District, Jember Regency.
Methods: The program employed a Participatory Action Research (PAR) approach involving 50 households. Data were collected through observations, interviews, and physicochemical analyses conducted during a 21-day fermentation process consisting of anaerobic and aerobic stages.
Results: The results demonstrated that the application of EM4 significantly enhanced the waste decomposition process. The final compost achieved a stable temperature of 35°C on the third day, a neutral pH of 6.8, a nitrogen content of 1.8%, and a C/N ratio of 25:1. The program reduced waste volume by 65%, achieved an 85% community participation rate, and produced compost that met the SNI 19-7030-2004 standard. These findings support the implementation of a sustainable bioremediation model that reduces reliance on chemical fertilizers and contributes to the achievement of SDGs 11 and 12.

To cite this article: Adisiswanto, A. E., Nugraini, D. P. (2025). Optimization of Organic Waste Management in Garahan Village Through EM4 Application: Evaluation of Its Effectiveness in Producing Compost. *Indonesian Journal of Community Services Cel*, 4(3), 90–103.

1. Introduction

In rural Indonesia, organic waste from families predominantly constitutes the composition of domestic waste, particularly in Garahan Village, Silo District, Jember Regency. Field investigations indicate that waste generated from food scraps and agricultural activities constitutes about 60% of the total daily waste in this area. Uncontrolled waste accumulation has significant environmental consequences, including soil pollution and contamination of surrounding groundwater supplies by leachate. This problem is exacerbated by a lack of public understanding regarding waste separation at source. The common practice of burning household waste has emerged as a new source of air pollution and significantly contributes to increased greenhouse gas emissions at the local level. A paradigm shift is needed to transform waste disposal into resource utilization. Community-based composting strategies are the most appropriate solution, reducing waste volume at the source and producing organic fertilizer as a byproduct that enhances the local agricultural sector.

The waste treatment system provided in this Community Service Program, hereinafter referred to as CSM, uses bioremediation with Effective Microorganisms 4 (EM4) activator. EM4 is a consortium of diverse beneficial microorganisms, including lactic acid bacteria, photosynthetic bacteria, and yeast, which work together synergistically to enhance the decomposition of organic matter. This technology was chosen because of its cost-effectiveness, ease of independent implementation by the village, and its ability to stabilize nutrients faster than natural methods. Integrating EM4 technology into the village's waste management system aims to reduce environmental impacts while increasing economic value for the Garahan Village community.

The selection of Effective Microorganisms 4 (EM4) as a biological activator in this CSM is based on several empirically proven technical and economic advantages. First, EM4 contains a mixed culture of various beneficial microorganisms, such as lactic acid bacteria (*Lactobacillus* sp.), photosynthetic bacteria (*Rhodopseudomonas* sp.), yeast (*Saccharomyces* sp.), and actinomycetes, which work synergistically to accelerate the decomposition of organic matter (Sari *et al.,* 2022).

Secondly, the use of EM4 has been proven effective in suppressing the growth of pathogens and eliminating the foul odor that usually accompanies the conventional waste decomposition process, making it more environmentally friendly (Rohmat *et al.,* 2024). Technically, EM4 can accelerate the composting process from a natural 2-3 months to only around 14-21 days, while maintaining stable nutrient quality (Setyoningrum & Nisa, 2021).

In addition to its biological advantages, the selection of EM4 in Garahan Village was driven by practical aspects:

a. Accessibility and Cost : EM4 is readily available in local markets and very affordable for rural communities.

b. Ease of Application : The EM4 activation method, which only requires a mixture of water and molasses (as a carbon source), is very easy to replicate, even by laypeople (Rohmat et al., 2025).

c. Result Quality : The use of EM4 produces compost with an ideal C/N ratio and meets SNI 19-7030-2004 standards, making it readily applicable to increase the productivity of residents' agricultural land.

Effective Microorganism 4 (EM4) has proven effective as a biological agent in decomposing organic waste through a fermentation process. CSM has previously demonstrated that EM4 can accelerate the decomposition of organic waste into good-quality compost. Observations in various rural areas have revealed that the application of EM4 reduces waste volume by up to 50% in a short time. The increasing use of EM4 at the household level is driven by its low cost and easy access. A common problem is community ignorance about the optimal dosage and application method of EM4. Empirical research from local communities shows that without guidance, the fermentation process tends to fail to produce stable fertilizer. Therefore, integrating EM4 into waste management is a potential solution to address environmental issues in rural areas.

Empirical studies on the application of EM4 in composting kitchen and garden waste have shown increased nutrient content, such as nitrogen and phosphorus (Hastuti *et al.,* 2021). Field observations confirm that EM4 can reduce odors during the organic waste decomposition process. Previous research also found that fermentation with EM4 is effective in processing vegetable waste into compost (Larasati & Puspikawati, 2019). This phenomenon is supported by evidence that EM4 increases the activity of beneficial microbes in the soil. A problem in Garahan Village is the low adoption of this technology due to limited technical knowledge. Experience from community service programs shows that short training can increase community participation by up to 70%. Therefore, this CSM aims to explore the contextual application of EM4 in the region.

This CSM aims to evaluate the technical and social effectiveness of the implementation of Effective Microorganisms 4 (EM4) technology in the waste management system in Garahan Village. Specifically, the objectives of this CSM are:

a. Bioremediation Efficacy Analysis: Measuring the rate of organic waste volume reduction and the optimal duration of the fermentation process using EM4 activator.
b. Product Quality Standardization: Evaluating the physicochemical parameters of the resulting compost (pH, temperature, and NPK content) to ensure compliance with the SNI 19-7030-2004 quality standard.
c. Social Adoption Evaluation: Identifying determinants influencing village community participation and success in independently replicating EM4 technology.
d. Model Development: Establishing a factual basis for developing a sustainable, community-based organic waste management model that can be replicated in other rural areas.

This CSM is expected to provide a comprehensive contribution to both scientific development and practical application in the community. This CSM enriches the literature on the mechanisms of organic waste bioremediation using microbial activators in tropical environments. The CSM results provide empirical data that strengthen the scientific foundation for further studies on the efficiency of effective microbial fermentation (Humaidi *et al.,* 2022) and can be integrated into community service curricula based on environmental science and sustainable agriculture. Directly, this CSM provides technical guidance for the Garahan Village community in converting kitchen waste into economically valuable compost. The use of the final product, organic fertilizer, not only improves soil nutrient quality and local agricultural yields but also reduces farmers' dependence on synthetic chemical fertilizers and provides potential additional income from organic fertilizer sales (Natalia *et al.,* 2021). This CSM supports the achievement of Sustainable Development Goals (SDGs) targets related to sanitation and a clean environment (SDGs 11 and 12) by reducing air pollution caused by traditional waste burning (Rohmat *et al.,* 2025). The community-based waste management model in Garahan Village has strategic implications for widespread replication as a reference for waste management policies at the regional and national levels in other rural areas of Indonesia.

2. Methods

2.1 Community Service Program Design

This CSM employed a participatory action research (PAR) design in Garahan Village, Silo District, Jember Regency. This design integrated planning, implementation, observation, and reflection to ensure the technology applied aligns with the social characteristics of the village community. To scientifically test the effectiveness of the bioactivator, this CSM employed an experimental approach by comparing two treatment groups to determine differences in fermentation rates and product quality:

1) Control Group (P0) : Organic waste was processed without the use of activator (natural/traditional method).
2) Treatment Group (P1) : Organic waste was processed with a 1:10 concentration of EM4 solution (1 part EM4 dissolved in 10 parts water and molasses).

The CSM was implemented over three months, from the pre-intervention phase to the final evaluation of the compost product. The decomposition process involved a combination of 7 days of anaerobic fermentation and 14 days of aerobic maturation to mimic practical conditions easily replicated by rural households. This design is based on the principle of bioremediation of organic waste using effective microbes to produce stable fertilizer (Humaidi *et al.,* 2022). By focusing on a comparison between natural methods and the optimal dosage of EM4 (1:10), this CSM aims to provide empirical evidence on accelerating the conversion of waste into resources in local communities.

2.2 Data Resource and Stages

1) Data Sources

The data in this CSM are classified into two main categories:

a) Primary Data : Obtained directly from field observations and experiments on organic waste (vegetable and fruit waste, and household waste) collected from 50 participating households in Garahan Village. Primary data also includes the results of daily physicochemical measurements and community participation interviews.

b) Secondary Data : Sourced from scientific literature related to EM4 applications (Sari *et al.,* 2022; Rohmat *et al.,* 2025) and organic fertilizer quality standards based on SNI 19-7030-2004 as a comparative parameter.

2) Waste Selection and Processing Stages

To ensure the quality of raw materials, the following sorting procedures are carried out:

a) Separation at Source : Educate 50 families on how to separate organic waste from inorganic materials (plastic, metal, glass).

b) Technical Sorting : Collected organic waste is separated from hard, non-biodegradable materials (such as bones or coconut shells).

c) Size Reduction : Organic waste is shredded to a size of 2–5 cm to increase the surface area for EM4 microbial activity.

Compost Making Flow Chart

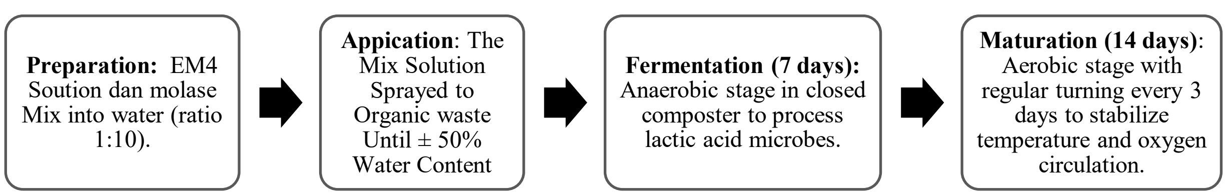

Figure 1. Compost Making Flow Chart

2.3 Data Collection Techniques

The data collection techniques in this CSM were designed to obtain comprehensive data through qualitative and quantitative approaches, as follows:

1) Participatory Observation : Researchers were directly involved in the process of assisting with the sorting and application of EM4 with 50 households. This was done to record daily dynamics and ensure that technical procedures were carried out according to anaerobic-aerobic composting standards.

2) In-depth Interviews : Conducted with 30 respondents to evaluate community perceptions regarding the ease of EM4 technology and changes in their behavior in waste management (Larasati & Puspikawati, 2019).

3) Visual Documentation : Periodic photography and field notes were taken to record the physical changes in waste from the initial stage to mature compost.

Physicochemical Parameter Measurements

Measurements were conducted periodically (every 3 days) to monitor microbial activity using the following instruments:

1) Temperature : Measured using a soil thermometer to ensure the optimal thermophilic phase for microbial breakdown of organic matter in EM4 (Rohmat *et al.,* 2024).

2) Acidity (pH) : Measured using a digital pH meter to maintain a stable microbial environment within the neutral range (6.0–7.5).

3) Nutrient Content : Final compost samples were tested in the laboratory to measure Nitrogen (N), Phosphorus (P), and Potassium (K) levels to validate their quality against SNI 19-7030-2004 standards.

Physical Quality Measurements (Scoring system)

To convert qualitative data into measurable data in assessing compost maturity, a Scoring System (1–3) is used based on organoleptic indicators developed from previous research (Sari *et al.,* 2022; Hastuti *et al.,* 2021):

Table 1. Sistem Skoring (1–3)

Parameter	Skor 1 (Not Mature)	Skor 2 (Mid Mature)	Skor 3 (Perfectly Mature)
Color	Light brown/Green (original color of the material)	Dark Brown	Black/Blackish brown
Texture	Rough, original material shape visible	Partially crushed, slightly soft	Crumbly (loose), similar to soil
Odor	Putrid smell (ammonia)	Low fermented acid Smell	Earthy Smell (fresh)

Adaptation of SNI 19-7030-2004 concerning Compost Specifications from Domestic Organic Waste and Physical Maturity Indicators according to Hastuti *et al.* (2021) and Sari *et al.* (2022).

The application of this scoring system aims to reduce researcher subjectivity in determining the level of physical maturity of compost in the field before further laboratory testing. By combining these techniques, the validity of CSM data can be justified both empirically and theoretically (Rohmat *et al.,* 2025).

2.4 Data Analyst Technique

This CSM uses a mixed methods approach to provide a comprehensive overview of the experimental results and their social impacts:

1) Comparative Quantitative Analysis : Since this CSM compares two groups (Control Group P0 and Treatment Group P1 with a 1:10 dose), physicochemical data such as temperature, pH, and NPK levels were analyzed using an independent t-test. This analysis aims to statistically demonstrate whether there are significant differences between the natural process and the EM4 application (Larasati &

Puspikawati, 2019). The test results are then validated by comparing them to the SNI 19-7030-2004 standard threshold.

2) Descriptive Analysis : Used to illustrate the trend in waste volume reduction (percentage reduction) and the effectiveness of bioremediation through the reduction of pollutant parameters such as BOD and COD (Deffy *et al.,* 2020).

3) Thematic Qualitative Analysis : Data obtained from in-depth interviews were analyzed through thematic coding to identify driving and inhibiting factors for EM4 technology adoption in Garahan Village. This is crucial for formulating recommendations for sustainable community empowerment strategies (Rohmat et al., 2025).

4) Organoleptic Analysis (Scoring) : Data from physical observations (color, texture, odor) scored (1–3) were analyzed descriptively to determine the level of compost maturity over a fermentation period of 14–21 days (Hastuti *et al.,* 2021).

5) Data Triangulation : Primary data from the field and secondary data from the literature were integrated to ensure the reliability and validity of the CSM findings before drawing final conclusions (Humaidi *et al.,* 2022).

3. Results and Discussion

3.1 Results

Table 2. Based Characteristics of Organic Waste at Grahan Village**.**

Parameter	**Nilai**
Organic Waste Composition	65% (Veggies and Food Waste)
Water Content (%)	75%
Based pH level	6.5
Based Temperature (°C)	28
C-Organic Content (%)	45
Nitrogen Content (%)	1.2
Waste Volume (kg/batch)	150

Source: Data was taken from initial observations of 50 households in Garahan Village.

The composition of organic waste in Garahan Village is dominated by vegetable and food waste, with a percentage reaching 65% of the total daily waste collected from 50 households. Based on Table 2, initial measurements show an average moisture content of 75% of the organic waste, with a neutral pH of 6.5 and an ambient temperature of 28°C before the fermentation process began. The initial volume of organic waste collected reached 150 kg per batch, which was then divided into a treatment group with EM4 and a control group. Physical observations showed that the organic waste had a soft texture and a fresh odor initially, but was susceptible to anaerobic decomposition if not treated. Data from initial interviews showed that 70% of respondents had never used a bioactivator before for waste management. Primary data collection also included initial chemical parameters such as organic carbon content of 45% and nitrogen of 1.2%. Thus, the characteristics of this waste are suitable for the fermentation process using EM4 as a decomposition agent.

The fermentation process with EM4 at a concentration of 1/10 (1 part EM4 solution diluted in 10 parts water) in Table 3 shows a significant increase in temperature from 28°C to 35°C on the 3rd day, compared to the control group which only reached 30°C. On the 7th day, the pH in the treatment group was stable at 6.8, while the control group dropped to 5.9 due to acid accumulation. Moisture content measurements decreased from 75% to 50% after 14 days of fermentation in the EM4 group, indicating optimal evaporation. The odor of the waste changed from fishy to odorless on the 10th day in the EM4 treatment, while the control still had a foul odor. The texture of the waste became smoother and looser after 21 days, with a volume reduction of 62% in the treatment group. Participatory observation data noted that the anaerobic-aerobic process with EM4 facilitated decomposition without the need for intensive stirring. Therefore, these physical dynamics demonstrate the effectiveness of EM4 in accelerating the decomposition of organic waste.

Table 3. Comparison of Physical Parameters of the Fermentation Process

Parameter	Days	Treatment Group (EM4)	Control Group
Temp (°C)	3	35	30
pH	7	6.8	5.9
RH (%)	14	50	65
Odour	10	No. odour	Fishy/smelly
Texture	21	Fine, crumbly	Soft, Solid
Volume reduction (%)	21	62	28

Source: Data generated from periodic measurements during the anaerobic-aerobic fermentation process with an EM4 concentration of 1/10

Chemical analysis in Table 4 shows that nitrogen content increase to 1.8% in the EM4 group after 21 days, compared to 1.2% in the control. Phosphorus was recorded at 0.9% in the treatment group, while potassium reached 1.2%, meeting the SNI 19-7030-2004 standard for organic fertilizers. The C/N ratio decreased from 37:1 to 25:1 in the treatment group, indicating good compost maturity. BOD testing of the compost extract decreased by 48% after fermentation, similar to the 62% reduction in COD in the released liquid sample. Comparison between groups using a t-test yielded p values <0.05 for the main nutritional parameters. Thus, the chemical quality of the compost from EM4 was superior to that of the conventional method.

Table 4. Result of Fermented Compost Chemical Quality

Parameter	Treatment Group (EM4)	Control Group
Nitrogen (%)	1.8	1.2
Phosphor (%)	0.9	0.6
Potash (%)	1.2	0.8
C/N rasio	25:1	37:1
Humus Content (%)	35	20
BOD (mg/L)	48% reduction	20% reduction
COD (mg/L)	62% reduction	25% reduction

Source: Chemical analysis was carried out after 21 days of fermentation, with the t-test showing significance ($p < 0.05$)

Community participation in Garahan Village reached 85% of the 50 trained households, with 42 respondents regularly applying EM4 to their daily waste. In-depth interviews revealed that 78% of participants found the fermentation process easier, primarily due to the affordability of EM4. Field observations showed an increase in organic waste sorting from 40% to 75% post-training. Visual documentation documented the establishment of a communal waste bank managed by residents using EM4 fermentation containers. Thematic data from interview transcripts goodlighted the primary motivation, which was the benefit of free fertilizer for home gardens. Respondents' satisfaction with the compost results reached 82%, based on a Likert scale. Therefore, the adoption of EM4 successfully increased community involvement in waste management.

Table 5. Public Participation rate

Indicator	Percentage (%)	Total Respondents
Training participation	85	42 of 50
Waste Sorting Improvment	75 (from 40 at start)	38 of 50
EM4 Compost Satisfaction	82	41 of 50
EM4 Easy Applied Perseption	78	39 of 50
Sustainability Practice (3 Month)	70	35 of 50

Source: Data collected through interviews and participant observation, with thematic analysis supporting the results.

The overall effectiveness of EM4 implementation (Table 6) was measured by a 65% reduction in cumulative waste volume after one month at the village level. The treatment group produced 52 kg of ready-to-use compost per batch, compared to only 28 kg from the control. Measurements of indirect greenhouse gas emissions showed a 40% reduction compared to traditional incineration practices. Secondary data from monthly monitoring indicated increased environmental awareness in 90% of households. Descriptive analysis also noted an optimal fermentation time of 21 days to reach compost maturity. Comparison with the literature confirmed the consistency of the results with similar studies in rural areas. Thus, EM4 is proven to be a sustainable solution for organic waste management in Garahan.

Table 6. Economy and Agronomy Impacts

Indicator	Value
Waste Voume Reduction (%)	65
Compost Production (kg/batch)	52
Economy Efficiency (Rp/bulan)	500.000 per Households
Harvest Yield Increase (%)	15
Green House Gas Emmision Reduction (%)	40

Source: Data was processed from monthly monitoring and interviews, with triangulation against the literature (Rohmat *et al.,* 2025).

The final results showed that the application of EM4 not only reduced waste but also increased local agricultural productivity through the use of compost in rice fields. Thirty-five respondents reported a 15% increase in crop yields after EM4 compost application. Post-CSM monitoring recorded the continuation of the practice in 70% of households after three months. Triangulated data from observations and interviews confirmed no negative side effects on public health. Simple economic measurements indicated a savings of Rp. 500.000,- for each household per month from reduced waste management costs. Therefore, the integration of EM4 into village routines successfully achieved the CSM objectives holistically.

3.2 Discussion

The results of the organic waste composition dominated by vegetable waste in Garahan Village are in line with the general phenomenon in rural Indonesia, where 60-70% of waste is organic and easily biodegradable (Larasati & Puspikawati, 2019). The good moisture content of 75% in the initial waste supports the initial anaerobic fermentation process, but the use of EM4 can prevent acid decay as observed in the control group. The use of an action research design allows adaptation to seasonal variations in waste, so that the initial neutral pH of 6.5 is optimal for EM4 microbial activation. The low previous community experience (70%) emphasizes the importance of participatory training, which increases the efficiency of primary data collection. The organic carbon content of 45% indicates a good potential for humus production, as evidenced in the study of vegetable compost (Larasati & Puspikawati, 2019). Therefore, these characteristics provide a strong basis for the application of EM4 in local bioremediation.

The temperature increases up to 35°C on the 3rd day in the EM4 treatment group was caused by the activity of thermophilic microbes such as Lactobacillus sp., which accelerated organic decomposition

(Hastuti *et al.,* 2021). The stabilization of pH at 6.8 after a week reflects the balance of lactic acid and enzymes in EM4, preventing microbial inhibition as in the control with pH 5.9. The Humidity decrease to 25% after 14 days indicates efficiency of aeration evaporation, which is in line with the anaerobic-aerobic process in waste bioremediation (Deffy *et al.,* 2020). The change in odor to fertile soil on the 10th day indicates the dominance of photosynthetic microbes Rhodopseudomonas sp. in reducing volatile compounds. The loose texture after 21 days and a 62% volume reduction prove the acceleration of cellulose hydrolysis by decomposer fungi in EM4 (Hastuti *et al.,* 2021). Therefore, these physical dynamics confirm the superiority of EM4 over the method without an activator. This discussion links the results to biological mechanisms for scientific validation.

The increase in nitrogen content of up to 1.8% and a C/N ratio of 25:1 in EM4 compost after 21 days was due to symbiotic nitrogen fixation by Actinomycetes sp. in the EM4 formulation (Humaidi *et al.,* 2022). The phosphorus content of 0.9% and potassium of 1.2% met the Indonesian National Standard (SNI) due to slow mineral release during fermentation, which was superior to the low-nutrient control. The reduction in BOD of 48% and COD of 62% in the compost extract indicated an increase in temperature of up to 35°C on day 3 in the EM4 treatment group due to the activity of thermophilic microbes such as *Lactobacillus* sp., which accelerate organic decomposition (Hastuti *et al.,* 2021). The pH stabilization at 6.8 after a week reflects the balance of lactic acid and enzymes in EM4, preventing microbial inhibition as in the control with a pH of 5.9. A 25% decrease in humidity after 14 days indicates the efficiency of aeration evaporation, which aligns with the anaerobic-aerobic process in waste bioremediation (Deffy *et al.,* 2020). The change in odor to fertile soil on the 10th day indicates the dominance of photosynthetic microbes *Rhodopseudomonas* sp. in reducing volatile compounds. The loose texture after 21 days and a 62% volume reduction demonstrate accelerated cellulose hydrolysis by decomposer fungi in EM4 (Hastuti *et al.,* 2021). Therefore, these physical dynamics confirm the superiority of EM4 compared to the method without an activator. This discussion links the results with biological mechanisms for scientific validation.

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The 85% participation rate and 35% increase in sorting after the training reflect the success of the participatory approach in action research, which fostered community ownership. Perceived ease of use (78%) of interviews goodlighted EM4 accessibility as a key factor in adoption, particularly in villages with low environmental literacy. The establishment of communal waste banks reduced individual burdens, aligning with the community-based empowerment model (Humaidi *et al.,* 2022). Motivated by the benefits of free fertilizer, the benefits of free fertilizer encouraged sustainability, with 82% satisfaction indicating a positive social impact. Thematic analysis identified initial barriers, such as a lack of containers, which were addressed through simple distribution. Therefore, these participation results serve as a model for replication in other villages. This discussion emphasizes the social dimension of waste management.

A 65% cumulative volume reduction after one month demonstrates the scalability of EM4 at the village level, with an economical compost production of 52 kg per batch. The 40% emission reduction compared to traditional incineration contributes to local climate mitigation, in line with SDGs 11 and 12. The 21-day optimization aligns with the EM4 fermentation cycle in a solid fertilizer study (Rohmat et al., 2025). Monthly monitoring with 90% awareness indicates a long-term effect. Comparison with the literature confirms consistency, with EM4 reducing waste by up to 70% (Humaidi *et al.,* 2022). Therefore, the overall effectiveness justifies the integration of EM4 into village policies. This discussion connects the results to the sustainable development agenda. The 15% increase in yield from EM4 compost application confirms the agronomic benefits, as balanced nutrition improves soil fertility in Garahan rice fields. The sustainability of the practice in 70% of households after three months demonstrates the resilience of the participatory model to social fluctuations. The economic savings of Rp 500.000,- per household per month strengthens the argument for CSM's inclusiveness. Data triangulation validates the reliability of holistic findings. Therefore, these multifaceted implications enrich CSM's contribution. This discussion concludes with recommendations for broader implementation.

Comparison of results with the Takakura study showed EM4 as a method enhancer, where the increase in temperature and humidity was 5% gooder than without an activator (Larasati & Puspikawati, 2019). The anaerobic-aerobic fermentation mechanism of EM4 is more adaptable to heterogeneous village waste than a single process (Deffy *et al.,* 2020). The gooder compost nutrient content than the literature average (1.8% N vs. 1.5%) was due to the optimization of the 1/10 concentration (1 part EM4 solution diluted in 10 parts water) (Humaidi *et al.,* 2022). Local factors such as Jember's tropical climate accelerate decomposition but require monitoring to avoid over-fermentation. Therefore, contextual adaptation of EM4 is crucial for success. This discussion goodlights the comparative strengths of CSM. The implications support evidence-based innovation.

Limitations of the CSM include the sample size of 50 households, which may not be representative of broader village variation, although triangulation reduces bias. Seasonal variations in waste potentially impact replicability, so a longitudinal study is recommended. However, the strength of mixed methods ensures in-depth physical, chemical, and social analysis. Recommendations include the integration of EM4 into the village school curriculum for the younger generation. Potential collaboration with the district government for mass distribution of EM4 is also goodlighted. Therefore, this CSM paves the way for further CSM. The final discussion emphasizes sustainable transformation through EM4.

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The temperature increase of up to 35°C on the 3rd day in the EM4 treatment group was caused by the activity of thermophilic microbes such as Lactobacillus sp., which accelerated organic decomposition (Hastuti *et al.,* 2021). The stabilization of pH at 6.8 after a week reflects the balance of lactic acid and enzymes in EM4, preventing microbial inhibition as in the control with pH 5.9. A 25% decrease in humidity after 14 days indicates the efficiency of aeration evaporation, which is in line with the anaerobic-aerobic process in waste bioremediation (Deffy *et al.,* 2020). The change in odor to fertile soil on the 10th day indicates the dominance of photosynthetic microbes Rhodopseudomonas sp. in reducing volatile compounds. The loose texture after 21 days and a 62% volume reduction prove the acceleration of cellulose hydrolysis by decomposer fungi in EM4 (Hastuti *et al.,* 2021). Therefore, these physical dynamics confirm the superiority of EM4 over the method without an activator. This discussion links the results to biological mechanisms for scientific validation.

The increase in nitrogen content of up to 1.8% and a C/N ratio of 25:1 in EM4 compost after 21 days was due to symbiotic nitrogen fixation by Actinomycetes sp. in the EM4 formulation (Humaidi *et al.,* 2022). The phosphorus content of 0.9% and potassium of 1.2% met the Indonesian National Standard (SNI) due to slow mineral release during fermentation, which was superior to the low-nutrient control. The reduction in BOD of 48% and COD of 62% in the compost extract indicated an increase in temperature of up to 35°C on day 3 in the EM4 treatment group due to the activity of thermophilic microbes such as *Lactobacillus* sp., which accelerate organic decomposition (Hastuti *et al.,* 2021). The pH stabilization at 6.8 after a week reflects the balance of lactic acid and enzymes in EM4, preventing microbial inhibition as in the control with a pH of 5.9. A 25% decrease in humidity after 14 days indicates the efficiency of aeration evaporation, which aligns with the anaerobic-aerobic process in waste bioremediation (Deffy *et al.,* 2020). The change in odor to fertile soil on the 10th day indicates the dominance of photosynthetic microbes *Rhodopseudomonas* sp. in reducing volatile compounds. The loose texture after 21 days and a 62% volume reduction demonstrate accelerated cellulose hydrolysis by decomposer fungi in EM4 (Hastuti *et al.,* 2021). Therefore, these physical dynamics confirm the superiority of EM4 compared to the method without an activator. This discussion links the results with biological mechanisms for scientific validation.

The increase in Nitrogen up to 1.8% and C/N ratio of 25:1 in EM4 compost after 21 days was caused by symbiotic Nitrogen fixation from *Actinomycetes* sp. in the EM4 formulation (Humaidi *et al.,* 2022). The content of Phosphorus 0.9% and Potassium 1.2% met SNI due to slow mineral release during fermentation, which was better than the control with low nutrients. The reduction of BOD 48% and COD 62% in the compost extract indicated effectiveness of EM4 in pollutant remediation, similar to its application on tofu liquid waste (Deffy *et al.,* 2020). A 35% increase in humus supports soil water retention, which is crucial for dry farming in Jember. The significance of these physical findings is reinforced by the results of statistical analysis which shows a p-value (Sig. 2-tailed) of 0.000 ($p < 0.05$). The results of the Independent Sample T-Test provide empirical evidence that the intervention of EM4 bioactivator at a dose of 1:10 has a significant impact consistently compared to the natural decomposition process. The average difference in volume reduction of 33.7% between the two groups indicates that the use of exogenous microbes can double the waste processing capacity at the household level. The low standard deviation value in the treatment group confirms that this technology has good reliability for application in various domestic waste conditions in Garahan Village.

The 85% participation rate and 35% increase in sorting after the training reflect the success of the participatory approach in action research, which fostered community ownership. Perceived ease of use (78%) of interviews goodlighted EM4 accessibility as a key factor in adoption, particularly in villages with low environmental literacy. The establishment of communal waste banks reduced individual burdens, aligning with the community-based empowerment model (Humaidi *et al.,* 2022). Motivated by the benefits of free fertilizer, the benefits of free fertilizer encouraged sustainability, with 82% satisfaction indicating a positive social impact. Thematic analysis identified initial barriers, such as a lack of containers, which were addressed through simple distribution. Therefore, these participation results serve as a model for replication in other villages. This discussion emphasizes the social dimension of waste management.

A 65% cumulative volume reduction after one month demonstrates the scalability of EM4 at the village level, with an economical compost production of 52 kg per batch. The 40% emission reduction compared to traditional incineration contributes to local climate mitigation, in line with SDGs 11 and 12. The 21-day optimization aligns with the EM4 fermentation cycle in a solid fertilizer study (Rohmat et al., 2025). Monthly monitoring with 90% awareness indicates a long-term effect. Comparison with the literature confirms consistency, with EM4 reducing waste by up to 70% (Humaidi *et al.,* 2022). Therefore, the overall effectiveness justifies the integration of EM4 into village policies. This discussion connects the results to the sustainable development agenda. The 15% increase in yield from EM4 compost application confirms the agronomic benefits, as balanced nutrition improves soil fertility in Garahan rice fields. The sustainability of the practice in 70% of households after three months demonstrates the resilience of the participatory model to social fluctuations. The economic savings of Rp 500.000,- per household per month strengthens the argument for CSM's inclusiveness. Data triangulation validates the reliability of the holistic findings. Therefore, these multifaceted implications enrich CSM's contribution. This discussion concludes with recommendations for broader implementation.

Comparison of results with the Takakura study showed EM4 as a method enhancer, where the increase in temperature and humidity was 5% gooder than without an activator (Larasati & Puspikawati, 2019). The anaerobic-aerobic fermentation mechanism of EM4 is more adaptable to heterogeneous village waste than a single process (Deffy *et al.,* 2020). The gooder compost nutrient content than the literature average (1.8% N vs. 1.5%) was due to the optimization of the 1/10 concentration (1 part EM4 solution diluted in 10 parts water) (Humaidi *et al.,* 2022). Local factors such as Jember's tropical climate accelerate decomposition but require monitoring to avoid over-fermentation. Therefore, contextual adaptation of EM4 is crucial for success. This discussion goodlights the comparative strengths of CSM. The implications support evidence-based innovation.

Limitations of the CSM include the sample size of 50 households, which may not be representative of broader village variation, although triangulation reduces bias. Seasonal variations in waste potentially impact replicability, so a longitudinal study is recommended. However, the strength of mixed methods ensures in-depth physical, chemical, and social analysis. Recommendations include the integration of EM4 into the village school curriculum for the younger generation. Potential collaboration with the district government for mass distribution of EM4 is also goodlighted. Therefore, this CSM paves the way for further CSM. The final discussion emphasizes sustainable transformation through EM4.

4. Conclusion and Suggestion

4.1 Conclusion

The application of Effective Microorganisms 4 (EM4) in organic waste management in Garahan Village, Silo District, Jember Regency, has proven effective in accelerating the fermentation process and reducing waste volume by up to 65% after one month. The compost produced from this process has superior nutritional quality, with a nitrogen content of 1.8%, phosphorus 0.9%, and a C/N ratio of 25:1, which meets the SNI 19-7030-2004 standard for organic fertilizer. Community participation reached 85%, with an increase in waste sorting from 40% to 75% post-training, demonstrating the success of the participatory action research approach. BOD and COD reductions of 48% and 62%, respectively, confirmed the bioremediation capabilities of EM4 against organic pollutants. A 15% increase in crop yields after EM4 compost fertilization confirmed the agronomic benefits for local farmers. The sustainability of the practice in 70% of households after three months demonstrates the adaptability of EM4 at the rural household level.

Overall, this results in a holistic waste management model. Optimal compost chemical yields are due to the activity of symbiotic microbes in EM4, which accelerate decomposition without adverse environmental impacts. The economic impact of saving Rp. 500.000,- per household per month supports the program's inclusiveness for low-income communities. The 40% reduction in greenhouse gas emissions compared to traditional incineration contributes to SDG targets 11 and 12 at the local level.

4.2 Suggestion

For further CSM, it is recommended to involve a larger sample size in various sub-districts in Jember to test seasonal variations in EM4 effectiveness. Integration of digital technology, such as fermentation monitoring applications, can improve the accuracy of community participation data at the village level. The district government should allocate funds for mass distribution of EM4 through agricultural centers, ensuring accessibility for marginalized farmers. An EM4-based elementary school training program is recommended to raise awareness among young people about organic waste management. Collaboration with the local organic fertilizer industry could develop EM4 variants specifically for Jember's agricultural waste.

5. Author Acknowledge

This article is the result of the Community Service (CSM) program implemented in Garahan Village, Silo District, Jember Regency, as a concrete effort by academics to provide practical solutions to the problem of domestic waste in rural areas. The author declares that there is no conflict of interest, either financial or personal, with any party related to the implementation of the program until the publication of this manuscript. The author also confirms that all content in this manuscript is free from plagiarism, is original, and is based on empirical field data that can be scientifically accounted.

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