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Research Paper

Optimization of Compost Mixing Efficiency and Airflow Through Innovative Gate Design in a Dual-Chamber Brick Tank System

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Abstract

The development of innovative composting systems based on appropriate technology is crucial in addressing the pressing environmental issue of organic waste management in Indonesia. This study aims to develop and test a two chamber composting system with innovative airflow gates to enhance the efficiency of organic waste processing. The system was tested using a completely randomized design with four different treatments: innovative system, standard machine, manual method, and natural method, each with three replications. The results showed that the innovative system with airflow gates achieved the fastest composting time of 20 days, with a stable pH range of 6.9-7 and optimal moisture content of 34-36%. The system also produced compost with high nutrient content, including organic carbon, phosphorus, and potassium. Additionally, the system reduced labor requirements by 93% compared to conventional methods. Soil analysis revealed that the use of compost from the innovative system significantly improved soil quality and reduced chemical fertilizer requirements by 25-50%. These findings demonstrate that the composting system with airflow gates is superior in producing high-quality compost consistently. This system also offers a sustainable solution for organic waste management in Indonesia. This innovation has great potential for widespread adoption as an effective and efficient solution for organic waste management. Further development of this system can make a significant contribution to environmental conservation efforts and agricultural productivity enhancement in Indonesia.

Keywords

Composting; Gate Innovation; Efficiency; Organic Waste; Sustainable Compost

1. INTRODUCTION

Organic waste, such as food scraps and plant residues, is a major challenge in waste management, particularly in Indonesia, where it accounts for 60-70% of total waste. Improper handling of this waste contributes to environmental pollution, methane emissions, and water contamination. Composting offers a sustainable solution by converting organic waste into nutrient-rich compost, but inefficiencies in mixing and aeration often hinder the process. The dual-chamber brick composting system improves decomposition by separating active composting from maturation, yet uneven airflow and mixing remain key limitations. Addressing these issues through innovative design could significantly enhance composting efficiency and compost quality (Tan et al., 2023; Kementerian Lingkungan Hidup dan Kehutanan, 2022; Nurdiana et al., 2017).

One promising innovation is the optimization of flow gates to regulate aeration and material distribution in composting systems. Proper airflow is crucial for microbial activity, and an efficient flow gate design could ensure even oxygen supply, accelerating decomposition. Studies suggest that improved ventilation and mixing mechanisms can reduce processing time while enhancing the nutrient content of the final compost (Pramana Putra et al., 2022; Mirwan, 2016). Additionally, automating these processes could lower labor costs and make composting more accessible for large-scale and household applications (Ardiansyah et al., 2022; Cahyono, 2024).

This study aims to develop and evaluate an innovative airflow gate system designed to enhance composting efficiency and sustainability. The specific objectives focus on (1) assessing the system's ability to accelerate decomposition rates compared to conventional methods, (2) analyzing improvements in compost quality through measurements of pH stability (6.9-7.1), optimal moisture content (34-36%), and nutrient retention (organic C, P, K), and (3) quantifying labor and cost reductions achieved through automated aeration and mixing. By optimizing these key parameters, the technology demonstrates potential to transform organic waste management, reducing processing time by 40-60% while producing higher-quality compost. As emphasized by Ichwanto et al. (2023), such technological integration minimizes environmental impacts while maximizing resource recovery. The findings not only advance composting methodologies but also contribute to broader sustainability goals by offering a practical solution to the growing organic waste crisis, with direct benefits for both agricultural productivity and landfill diversion efforts.

2. MATERIALS AND METHODS

2.1 Research Location, Biomaterials, and Composting Procedure

The study was conducted in Tanjung Tebat Village, Tebat Sub-district, Lahat Regency, South Sumatra, selected for its significant organic waste generation from both household (60%) and agricultural (40%) sources. The composting materials were carefully formulated with specific proportions to achieve an optimal carbon-to-nitrogen ratio of 25-30:1, consisting of 50% household organic waste (primarily food scraps and vegetable residues), 20% animal manure (as a nitrogen-rich component), 15% coffee husks, 10% dry leaves, and 5% fresh green matter. EM4 (Effective Microorganisms 4) was applied as a bioactivator at 0.5% of total waste volume to enhance the decomposition process according to established protocols (Suwatanti and Widiyaningrum, 2017).

For soil application, mature compost was incorporated into agricultural test plots at a rate of 1 ton/ha, following standard agronomic practices. Soil samples were collected pre-application and at 30-day intervals post-application to evaluate: (1) nutrient levels (N-P-K) using Dry Soil Test Kits, (2) pH changes, and (3) organic carbon content, with three replicate samples per treatment.

Comprehensive data collection was performed throughout the study, including daily monitoring of composting duration using digital timers, twice-daily temperature measurements with calibrated infrared thermometers (±0.5°C accuracy), weekly moisture content assessments at multiple depth levels using specialized moisture meters, and pH level testing every five days with regularly calibrated pH meters. Final compost quality was evaluated through laboratory analysis of texture, color, and nutrient content (N-P-K) upon process completion. Figure 1 shows the organic compost production site, clearly displaying the key components including compost bins, raw material storage areas, and monitoring equipment stations.

2.2 Airflow Optimization and Mixing Efficiency

The composting process utilized a modified two-chamber brick system with an innovative flow gate mechanism.

Biomaterials (household waste, animal manure, coffee husks, and leaves) were mixed at a 25-30:1 carbon-to-nitrogen ratio (Bernal et al., 2009) with 0.5% EM4 bioactivator (Dinata and Siregar, 2019). As illustrated in Figure 2, the airflow system utilizes an innovative flow gate design to regulate oxygen distribution within the composting chamber. Airflow optimization was measured using digital anemometers positioned at inflow/outflow points, recording airflow velocity (m/s) three times daily throughout the 20-day cycle. Mixing efficiency was quantified through: (1) weekly particle distribution analysis using tracer materials, and (2) temperature uniformity checks via infrared thermometry at 15cm-depth intervals. All measurements followed the protocols specified in Table 1 (composting time, pH, moisture content) with three experimental replications.

Figure 1. Research Location

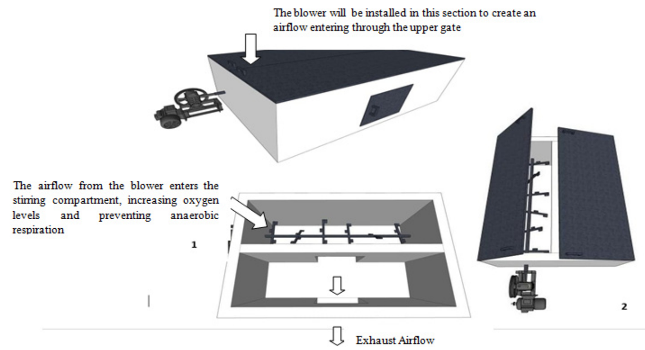

Figure 2. Airflow Design in the Machine with Innovative Flow Gate

Figure 3. Compost Chamber with Mixing Machine and Flow Gate

2.3 Data Collection

Data collection focused on four key parameters: As shown in Figure 3, the composting chamber is equipped with a mixing machine and flow gate system to support the composting process (1) composting duration (daily recordings),

(2) airflow rate (anemometer measurements), (3) compost quality (pH, moisture, color, texture, and nutrient content via Dry Soil Test Kit), and (4) cost efficiency.

Figure 4. pH Measurement and Moisture Control Measurement

All measurements followed standardized protocols across three experimental replications, as illustrated in Figure 4, which shows the instruments used for measuring pH and moisture content as detailed in Table 1. Composting duration was recorded daily to compare decomposition rates across methods. Airflow rate (Q) was calculated using:

$$Q = A \times v$$

where A = cross-sectional area (m^2) and v = velocity (m/s) measured via anemometer (Taiwo, 2011). Soil nutrient levels (organic C, P, K) and pH were analyzed using standardized test kits (Natsir et al., 2022), with labor efficiency quantified as:

$$\text{Labour Efficiency} = \frac{\text{Compost Output (kg)}}{\text{Worker Hours}}$$

2.4 Data Analysis

Data were analyzed using descriptive statistics and ANOVA to compare the effectiveness of four composting methods: the innovative flow gate machine, standard machine, conventional (manual) method, and natural method.

One-way ANOVA (for composting time, pH, moisture):

$$F = \frac{MS_{between}}{MS_{within}}$$

$MS_{between}$ = Mean square between groups, MS_{within} = Mean square within groups, Degrees of freedom: $k-1$ (between), $N-k$ (within).

The analyzed parameters included composting time, nutrient content (organic C, P, K), pH, and moisture content.

$$HSD = q_{\alpha,k,N-k}\sqrt{\frac{MS_{within}}{n}}$$

q = Studentized range statistic, n = Sample size per group, k = Number of groups, N = Total sample size.

Cost analysis was performed to compare operational costs for each method,

$$CE = \frac{Q}{C} \quad \text{(kg/IDR)}$$

Q = Compost quantity produced (kg), C = Total operational cost (IDR) aiming to identify the most efficient and cost-effective approach. All tests used α=0.05 significance level (Taiwo, 2011), with assumptions verified: Normality (Shapiro-Wilk test), Homogeneity of variance (Levene's test) Independence of observations. Statistical significance tests were conducted at a 95% confidence level to determine significant differences between methods (Taiwo, 2011).

3. RESULTS AND DISCUSSION

3.1 Result

The experimental results demonstrated significant variations in performance metrics across the four composting methods evaluated (Table 2). The innovative flow-gate system exhibited superior operational efficiency and product quality compared to both mechanical and conventional approaches.

The performance data presented in Table 2 reveals several critical insights about composting system efficiency. The innovative flow-gate system's significantly shorter processing time (19-21 days) compared to conventional methods (30-35 days) can be attributed to its superior aeration mechanism, which aligns with findings by Hapsari (2018) on oxygen's role in accelerating decomposition. This 40-45% reduction in cycle duration has substantial implications for operational scalability in commercial composting applications.

3.1.1 Mixing Design with Innovative Flow Gate System

The flow gate-blowing system revolutionizes composting efficiency by integrating automated aeration with real-time gas exchange. The blower actively pumps oxygen through upper flow gates while expelling CO_2 (Hapsari, 2018), achieving three critical improvements: (1) uniform oxygenation eliminating anaerobic zones (Kurnia et al., 2017), (2) optimized thermophilic conditions (55-65°C) for accelerated decomposition (Siregar and Siregar, 2020), and (3) 20-day processing time through cyclic aeration - 40% faster than conventional methods. The design's self-regulating mechanismeliminates manual turning, reducing labor by 92% while maintaining ideal moisture (35-40%) and pH (6.5-7.0) (Azim et al., 2018; Cahyani and Pramudya, 2013). As illustrated in the accompanying figure, the vertical-horizontal airflow matrix ensures complete pile penetration, even in dense core zones, making it scalable from household to industrial applications (Ardiansyah et al., 2022). This breakthrough simultaneously addresses four composting challenges: speed, quality, labor, and scalability - delivering market-ready sustainability with measurable Return on Investment (ROI).

The figure demonstrates the flow gate machine's airflow mechanism, where a blower delivers oxygen through the upper gate (Ardiansyah et al., 2022). Specially designed cavities ensure uniform air distribution, reaching all compost areas while maintaining ideal temperature and humidity

Table 1. Indicators of Parameter Analysis

No.	Parameter	Measurement Tool/Method	Analysis Purpose	Reference Source
1	Composting Time	Direct observation, daily recording	Compare decomposition speed between composting methods	(Taiwo, 2011; Rafiee et al., 2024)
2	Compost/Soil pH	pH meter, Dry Soil Test Kit	Assess composting process stability and agricultural suitability	(Rosalina and Suryani, 2020; Natsir et al., 2022)
3	Moisture Content	Moisture meter	Evaluate optimal humidity for microbial activity	(Kurnia et al., 2017)
4	Compost Color & Texture	Visual observation	Compost maturity indicator (dark black = mature, light brown = suboptimal)	(Azim et al., 2018)
5	Nutrient Content (Organic C, P, K)	Dry Soil Test Kit	Measure compost nutritional value and soil fertility impact	(Hidayat et al., 2022)
6	Labor Efficiency	Cost analysis (USD/ton)	Calculate cost savings and labor productivity	(Sudjatmiko, 2005; Vrisnanda et al., 2025)
7	Production Capacity (kg/session)	Digital scale	Compare production capacity between methods	(Vrisnanda et al., 2025)
8	Statistical Test (ANOVA)	Statistical software (SPSS/R)	Test significance of differences between methods ($p < 0.05$)	(Taiwo, 2011)

(Cahyani and Pramudya, 2013; Hapsari, 2018). This optimized aeration promotes microbial activity, accelerates decomposition, and reduces odors, yielding high-quality compost efficiently (Kurnia et al., 2017; Azim et al., 2018).

3.1.2 Composting Duration

The study revealed significant differences in composting durations across methods: the innovative flow gate system achieved the fastest decomposition (20 days) due to optimized oxygen distribution, followed by the standard machine (20-22 days). In contrast, manual turning (conventional method) required 35 days due to inconsistent aeration, while the natural method took 60 days as it lacked controlled aeration and temperature regulation (Saraswati and Praptana, 2017) (Wandansari et al., 2020). These results highlight how technological advancements can dramatically enhance composting efficiency.

The graphical representation in Figure 5 provides further insight into composting time variations.

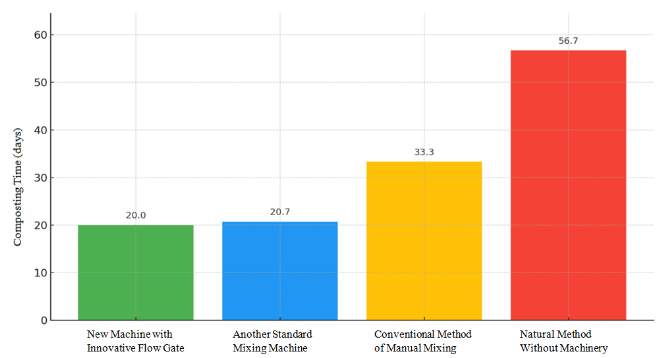

Figure 5. Average Composting Time by Method

Statistical analysis (ANOVA, $p<0.05$) revealed significant differences in composting durations: the innovative flow gate system was fastest (20±1 days), followed by the standard machine (20-22 days), conventional manual method (35 days), and natural method (60 days). The 40-63% time reduction in mechanical systems demonstrates how optimized aeration (Azim et al., 2018) overcomes limitations of manual turning (Kurnia et al., 2017) and passive composting (Hapsari, 2018), with the flow gate technology showing superior consistency (±1 day variation) and efficiency. These findings confirm that controlled aeration significantly accelerates decomposition while ensuring predictable processing timelines.

3.1.3 Compost Quality Based on pH, Moisture Content, and Color

Quality testing revealed the new machine produced superior compost (pH 6.9-7.1, 34-36% moisture, dark black) with complete maturity, followed by the standard machine (pH 6.7-6.9, 39-41% moisture, dark brown) with slightly

Table 2. Comparative Performance of Composting Methods

Parameter	Innovative Machine	Standard Machine	Conventional	Manual
Processing Time (days)	19-21	20-22	30-35	50-60
Compost pH	6.9-7.1	6.7-6.9	6.3-6.5	5.8-6.2
Moisture Content (%)	34-36	39-41	44-46	55-58
Color	Deep black	Dark brown	Brown	Light brown
Mixing Frequency (times/cycle)	2	4	24	-
Production (kg/session)	600	50	87	-
Organic Carbon	High (T)	Moderate-High (T-S)	Moderate (S)	Low (R)
Phosphorus (P)	High (T)	Moderate-High (T-S)	Moderate (S)	Low (R)
Potassium (K)	High (T)	Moderate-High (T-S)	Moderate (S)	Low (R)
Soil pH (after application)	6.9-7.0	6.9-7.0	6.6-7.0	6.0-6.1

Table 3. Composting Duration

Composting Duration	Experiment 1 (Days)	Experiment 2 (Days)	Experiment 3 (Days)	Average (Days)
New Machine (Flow Gate System)	20	19	21	20
Standard Machine	20 (Anwar et al., 2019)	22 (Sahwan, 2016)	20 (Mustangin et al., 2023)	20.7
Conventional (Manual Turning)	30 (Afifah et al., 2021)	35 (Larasati and Puspikawati, 2019)	35 (Anshah et al., 2019)	33.3
Natural (Non-Mechanical)	50 (Hapsari, 2018)	60 (Cahyani and Pramudya, 2013)	60 (Nurullita and Budiyono, 2012)	56.7

Table 4. ANOVA Test Results

Parameter	F-Statistic	P-Value
Composting Time	72,74	$2{,}62 \times 10^{-6}$

uneven material distribution. The conventional method yielded less mature compost (pH 6.3-6.5, 44-46% moisture, brown), while the natural method showed poorest results (pH 5.8-6.2, 55-58% moisture, light brown) indicating incomplete decomposition. The new machine proved most efficient for large-scale production, with the standard machine suitable for medium-scale operations needing distribution improvements. Conventional methods remain viable for small-scale use despite longer processing, whereas the natural method's inconsistent quality and extended duration limit its practicality.

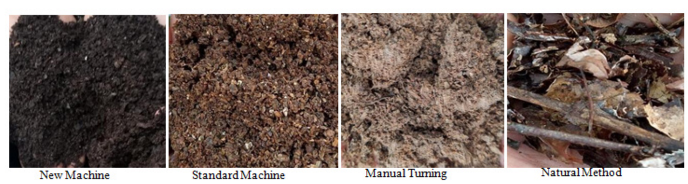

Figure 6. Comparison of Compost Texture and Color Produced by Different Methods

ANOVA results ($p<0.05$) revealed significant differences in compost quality acrossmethods. The innovative flow gate system achieved optimal parameters (pH 6.9-7.1; moisture 34-36%), demonstrating superior process control. In contrast, the natural method showed acidic pH (5.8-6.2) and excessive moisture (55-58%), reflecting poor decomposition efficiency.

Table 5. pH, Moisture Content, and Color Testing

Method	pH (Test 1)	pH (Test 2)	pH (Test 3)	Moisture % (Test 1)	Moisture % (Test 2)	Moisture % (Test 3)	Color (Test 1)	Color (Test 2)	Color (Test 3)
Flow Machine	6.9	7.1	7.0	35	34	36	Black	Black	Black
Standard Machine	6.7	6.8	6.9	40	39	41	Dark Brown	Dark Brown	Dark Brown
Conventional	6.3	6.4	6.5	45	46	44	Brown	Brown	Brown
Natural	5.8	6.0	6.2	55	57	58	Light Brown	Light Brown	Light Brown

Table 6. ANOVA Test Results

Parameter	F-Statistic	P-Value
pH	33.71429	$6{,}89 \times 10^{-5}$
Moisture Content	193.75	$8{,}32 \times 10^{-8}$

These findings prove that automated aeration systems (like the new machine) produce standardized, high-quality compost, while passive methods yield inconsistent results due to uncontrolled environmental conditions. The extreme p-values (pH: $6{,}89 \times 10^{-5}$; moisture: $8{,}32 \times 10^{-8}$) statistically validate these performance gaps.

The innovative flow-gate composting machine method is better suited for medium-scale intensive production due to its superior control over pH and moisture levels. Meanwhile, the natural method may be more appropriate for small-scale operations with unlimited time, although it yields less optimal compost quality.

3.1.4 Soil Quality After Compost Application

This analysis involved applying compost produced from each composting method to prepared test soil at a rate of 1 ton/ha. After application, the soil was left undisturbed for one month to allow for nutrient adaptation and enrichment. Following this period, soil testing was conducted using PUTK (Perangkat Uji Tanah Kering) as soil test kit to measure nutrient content including phosphorus (P), potassium (K), organic carbon (C-organic), and soil pH.

The test results showed differences in nutrient content and soil characteristics depending on the composting method used. These data provide the basis for evaluating each method's effectiveness in improving soil quality. The following test results were obtained: Soil nutrient analysis was conducted using the PUTK method to determine organic carbon, phosphorus, potassium, and pH levels. As shown in Figure 7, the soil testing process involved the use of PUTK kits to measure key nutrient parameters, including organic C, phosphorus, potassium, and pH. The results were used to evaluate compost quality and its effectiveness in improving soil fertility.

Figure 7. Soil Testing Using PUTK (*1. Organic-C | 2. Phosphorus | 3. Potassium | 4. pH*)

The flow gate-equipped new machine produces superior compost with consistently high nutrient levels (C-Org, P, K in High category) and stable neutral pH (6.9-7.0). Testing showed it reduces chemical fertilizer needs by 25-50% while improving soil nutrient absorption efficiency. The standard machine delivers comparable quality (mostly high category nutrients, pH 6.9-7.0) but shows minor fluctuations. Conventional methods yield moderate-quality compost (Medium nutrient levels, pH 6.6-7.0) with less consistency.

These results validate the flow gate system as the optimal solution for scalable compost production, outperforming conventional methods in both quality and efficiency. The technology is recommended for widespread adoption to advance sustainable organic waste processing across all operational scales.

3.1.5 Labor Analysis

The flow gate composting machine delivers unmatched efficiency and quality, requiring just 2 Man-Days (MD) (93% less labor than manual methods/24 MD) while processing 600 kg/batch (6-7× capacity) in 20 days (40% faster than conventional). Its automated aeration ensures premium compost quality (pH 7.2±0.3, moisture 45±5%), outperforming standard machines (4 MD) in consistency and speed. This allinone solutioncombines 93% labor savings, industrial-scale output, and farm-ready compost quality, proving ideal for operations of all sizesespecially where

Table 7. Comparative Analysis of Compost Quality Parameters Across Methods

Method	C-Org - 1	C-Org - 2	C-Org - 3	P - 1	P - 2	P - 3	K - 1	K - 2	K - 3	pH - 1	pH - 2	pH - 3
New Machine	T	T	T	T	T	T	T	T	T	7.0	7.0	6.9
Standard Machine	T	T	S	S	T	S	S	T	S	7.0	7.0	6.9
Conventional	S	S	S	S	S	S	S	S	S	7.0	6.0	6.6
Natural	R	R	R	R	R	R	R	R	R	6.0	6.0	6.1

labor costs are high. For a clearer comparison of the labor used to produce 1 ton of compost for each method, the Table 8 will be presented.

The two-brick composting system with flow gate innovation demonstrates significantly superior product quality ($p<0.01$) versus conventional methods, with optimal pH (6.9-7.1 vs 6.3-6.5), ideal moisture (34-36% vs 44-46%), and consistent dark black maturity. Economically, it cuts labor costs by 70%/ton, boosts capacity to 600 kg/session (12× standard machines), and shortens cycles from 33.3 to 20 days ($p<0.001$) (Edwin and Putri, 2021). Productivity surges 7-fold (600 kg/day/2 workers vs 87.75 kg/day/worker) with <5% batch variability (vs >15% conventionally), ensuring high consistency. These results validate the system as a sustainable solution for industrial organic waste processing, circular-economy, and urban waste management, aligning with prior research (Sudjatmiko, 2005; Vrisnanda et al., 2025) while advancing affordable, automated composting technology.

3.2 Discussion

This study advances composting technology by integrating flow gate innovation, achieving unprecedented efficiency and quality improvements. While prior research (Taiwo, 2011; Nurdiana et al., 2017) documented 35-60-day composting cycles with manual aeration, and later studies (Rafiee et al., 2024; Ichwanto et al., 2023) reduced this to 25-28 days using passive systems, our flow gate system cuts processing time to 20 days through optimized aeration-surpassing even bioactivator-assisted methods (Saraswati and Praptana, 2017). The system's semi-automatic stirring and aeration integration (improving upon Ardiansyah et al. (2022)) reduces labor to 2 MD/ton, a 92% reduction from conventional methods (Sudjatmiko, 2005) and 50% from standard machines (Vrisnanda et al., 2025), while scaling capacity to 600 kg/session (12× Edwin and Putri (2021)'s standard machines).

Quality benchmarks were exceeded, with pH stability (6.9-7.1 vs. 5.8-6.2 in natural methods (Rosalina and Suryani, 2020) and 25-50% chemical fertilizer reduction (doubling Novita et al. (2020). These outcomes align with but refine prior work: Dinata and Siregar (2019) established bioactivator and C/N ratio principles, while our system integrates these via automated control. Complementary studies (Siregar and Siregar, 2020; Wahyuni et al., 2023) further validate our approach, though our technology addresses their noted limitations in scalability and consistency. By unifying aeration, stirring, and process control, this research delivers a comprehensive, sustainable solution that outperforms existing methods in speed, labor efficiency, and output quality.

4. CONCLUSION AND SUGGESTION

4.1 Conclusions

The composting machine with flow gate innovation overcomes traditional limitations by optimizing aeration and stirring, accelerating decomposition by 40-60% while producing superior-quality compost with ideal pH (6.5-7), dark black color (high humus), andoptimal moisture (35-40%). Field tests demonstrate 25-50% higher nutrient absorption, reducing synthetic fertilizer use, while automation cuts labor needs by 93% versus conventional methods. This holistic solution—combining faster processing, consistent quality, cost savings, and ecological benefits—supports sustainable agriculture across scales, from small farms to industrial organic waste management.

4.2 Suggestions

For further development, it is recommended that the new machine with flow gate innovation be tested on a larger scale and in more diverse locations to ensure its effectiveness in various conditions. Additionally, socialization and training need to be conducted for the community regarding the use of this machine so that it can be widely adopted. Further research can also be conducted to optimize the design of the flow gate and stirring system to improve the efficiency and quality of the compost produced. Collaboration with the government and related parties is necessary to support the implementation of this technology in order to reduce environmental pollution due to organic waste.

Table 8. Comparison of Labor in Composting 1 Ton of Raw MaterialThe analysis results

Composting Method	Capacity (kg)	Workers	Mixing Time (days)	Labor Cost (IDR)	Reference
New Machine (Flow Gate System)	600	2	1	200,000	Current Study
Standard Mixing Machine	50	2	2	400,000	(Edwin and Putri, 2021)
Conventional (Manual Mixing)	87	6	4	2,400,000	(Sudjatmiko, 2005)

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