AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Extending the shelf life of organic liquid fertilizer from food waste processing based on Masaro technology

Akhmad Zainal Abidin[a,*], Soen Steven[b], Novita Sari Siregar[a], Agatha Cecilia Hutahaean[a], Hafis Pratama Rendra Graha[a], Elsye Veradika Yemensia[a], Ernie S. A. Soekotjo[a,b], Ridwan P. Putra[a]

[a] *Department of Chemical Engineering, Faculty of Industrial Technology, Institut Teknologi Bandung, Bandung 40132, Indonesia*

[b] *Research Center For Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency (BRIN), KST BJ Habibie, Building 720 Puspiptek Area, South Tangerang, Banten 15314, Indonesia*

Article Info

Article history:
Received 8 July 2024
Revised 17 September 2024
Accepted 5 February 2025
Available online 28 February 2025

Keywords:
Amino acid,
Fatty acid,
Food waste,
Organic fertilizer,
Photo-oxidation

Abstract

Importance of the work: Food waste is an environmental issue in Indonesia that requires greater attention. One effort to address the problem is 'Masaro' (an abbreviation for "zero waste management" in Indonesian) technology, with its main product being organic liquid fertilizer. However, this fertilizer can experience pH escalation due to deterioration when it is oxidized. Therefore, a solution is needed to prolong its shelf life.

Objectives: To extend the shelf life of organic liquid fertilizer from food waste using Masaro technology.

Materials and Methods: Several types of food waste were chopped and then fermented in two stages to form a product. Variations were investigated in the organic waste type, the addition of phosphate buffer and the product storage conditions.

Results: The organic waste producing the highest pH (6−8) was mustard greens due to their carbohydrate content being the lowest. Phosphate buffer addition significantly maintained the pH levels at 3−4 for all food waste types, as well as enhancing the number of probiotic bacteria, reducing the presence of pathogenic bacteria and increasing the nutrient contents (amino acids and fatty acids) in the product. The optimal storage conditions for the liquid fertilizer produced were a temperature of 8−10°C without exposure to direct sunlight. On the other hand, high temperatures and greater light exposure expedited oxidation.

Main finding: The application of phosphate buffers, storage at low temperatures and no sunlight exposure significantly reduced fertilizer deterioration through oxidation. These findings should help to ensure the shelf life extension of organic liquid fertilizer to longer than 1 yr.

* Corresponding author.
E-mail address: aza@itb.ac.id (A.Z. Abidin)

https://doi.org/10.34044/j.anres.2025.59.1.03

Introduction

The estimate that only 60% of waste in Indonesia can be transported to the final disposal site (landfill) has been categorized as an outdated waste management paradigm based on collect-transport-dispose (Yemensia et al., 2023; Abidin et al., 2024c). Indonesian municipal waste in 2023 consisted of 39.33% food waste, 18.75% plastic waste, 12.64% wood waste and 11.54% paper waste, with the remainder including metals, clothes, glass, rubber products and other waste (KemenLHK, 2023). Thus, waste handling needs to be handled more effectively and comprehensively, especially by stakeholders and policy formulators.

Since food waste constitutes the largest portion, it merits the the top priority to find solutions to reduce this component because unmanaged waste causes unpleasant odors, is aesthetically displeasing and can be a disease source (Iravanian and Ravari, 2020). Furthermore, long-term food-waste disposal as a landfill can emit greenhouse gases, pollute the soil and endanger water ecosystems (Zhu et al., 2023; Febijanto et al., 2024).

Several food waste processing options have been proposed such as composting, direct usage as fertilizer, and maggot technology. However, composting tends to take months (Al-khadher et al., 2021). Direct use of waste is also interesting; however, nutrition uptake can be negatively impacted if the waste components are too large and hard, while maggot technology is limited by the breeding time and its performance is superior only for soft food waste (Nugroho et al., 2023; Steven et al., 2024).

In addition to these limited processing options, 'Masaro' technology has been introduced, which is the Indonesian abbreviation of 'Manajemen Sampah Zero' (zero waste management) which shifts the waste paradigm from a cost center to a profit center (Abidin et al., 2024d). It is a technology that provides a practical solution to the waste problem. Instead of going to landfill, under Masaro value is added to the waste to encourage more sustainable usage. To reach this goal, Masaro strongly emphasizes waste sorting at source as an important preliminary action—either in households, in waste-producing sectors (such as industries), in restaurants, or at landfill sites—followed by on-site waste processing. This involves sorting the waste into rapidly decaying organic waste (such as food items), slow-decaying organic waste (such as seeds and the hard peel of fruits), plastic film waste, recyclable waste and residue (such as paper, processed wood, branches and twigs, glass and metal objects).

Based on previous experience, Masaro technology has been applied in various areas such as Pasawahan region, Tinumpuk village, Cileunyi Kulon village, Cilegon village, MAN 2 Cirebon, Babakan Ciwaringin village and in cities in West Java. At all these sites, there has been reported satisfaction with the process by the local communities and regional heads because the application of Masaro technology has helped to solve the waste problem, leading to sustainability and creating a circular economy from the sale of products such as organic liquid fertilizer, organic liquid feed concentrate, compost, organic pesticides and fuel (Abidin et al., 2021a; Abidin et al., 2021b; Yemensia et al., 2023; Abidin et al., 2024c)

Applying Masaro technology, food waste (being s easily decomposed) is processed into organic liquid fertilizer using enzymatic fermentation to decompose the organic substances in the food waste (Abidin et al., 2024b). Several factors influence the fermentation performance, including temperature, organic substance content, aeration and the bioreactor color. Based on a related study, it was concluded that the optimal production process should be carried out without aeration, using a dark blue bioreactor and a stirring frequency of once daily to provide organic liquid fertilizer with a guaranteed shelf life of 1 yr (Abidin et al., 2024a).

Organic liquid fertilizer production should be accompanied by a quality guarantee regarding its shelf life to support a circular economy and sustainable development (Stella et al., 2019). Product usage of 1 yr is hypothesized to be valid when the product is not stored at room temperature and not directly exposed to sunlight. If the storage method is not as recommended, the product then deterioration can be swifter. Satinder (2012) reported the shelf life of microorganisms present in organic liquid fertilizer was 2 yr with a storage temperature not exceeding 55°C.

The pH is the most important parameter that reflects the stability of organic liquid fertilizer, which can be stabilized by adding a buffer. According to Zulfarosda et al. (2022), a phosphate buffer maintained the fertilizer pH in the optimal range, acting as a pH-lowering solution in liquid fertilizer, without having a negative effect on plants. Hartman et al. (2016) reinforced the role of phosphate as a trigger in the systemic acquired resistance mechanism in plants and in inducing the growth of plant roots. Therefore, apart from determining the optimal fermentation for liquid fertilizer, there is value in extending the shelf life of organic liquid fertilizer.

Therefore, the objective of the current study was to examine the effects of food waste type, phosphate buffer addition and storage conditions on the pH and color change of

organic liquid fertilizer. The food waste types investigated were mangoes, pineapples, mustard greens and oranges. Subsequently, the buffer concentration was used at the level of 5%, and the storage conditions investigated were storage temperature and sunlight exposure. The monitored results parameters were pH and color, as well as the contents of microbes, amino acids and fatty acids.

Materials and Methods

Food waste preparation

Several types of food waste were derived from fruits and vegetables (mustard greens, oranges, pineapples and mangoes) and were collected from the local market in Caringin, Bandung, West Java, Indonesia. Initially, the collected waste samples were pulverized until has a slurry form to ease the fermentation process (Fig. 1).

Main experiments

The fermentation process was divided into two stages as schematized in Fig. 1. The first stage involved reacting 2 L of each chopped food waste sample in a bioreactor with a proprietary Masaro I catalyst. Water (5 L) was included as a solvent. Then, all tested mixtures were stirred once daily and the process continued until all the solids had settled to the bottom of the bioreactor. The substances from the first stage of fermentation were filtered using a solid-liquid separator. Next, the filtered solids were separated and the liquid was placed in the bioreactor. Subsequently, the second stage involved the reaction of the substances from the first stage in the same bioreactor with a proprietary Masaro II catalyst. Water was added until the total volume was five times greater than the initial volume. The mixture was stirred once daily. The reaction was considered complete when the mixture was pale yellow and had a yeasty odor.

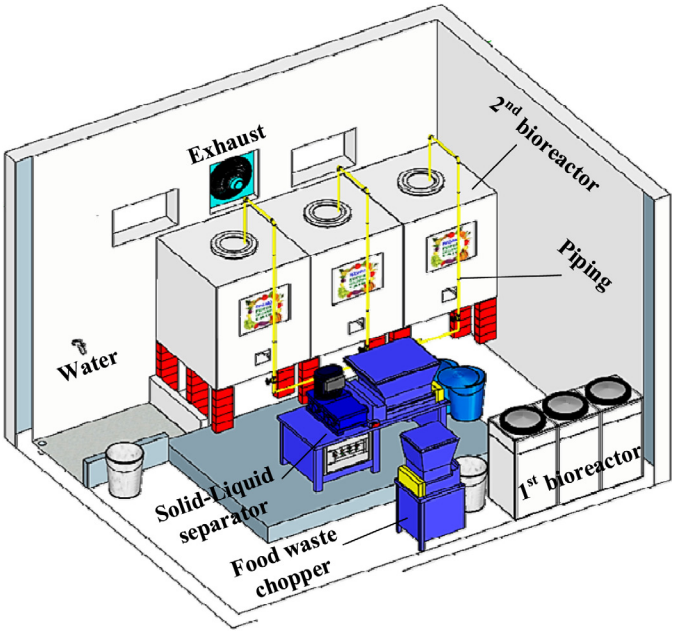

Fig. 1 Production process of organic liquid fertilizer from food waste using Masaro technology (adapted from Abidin et al., 2024b)

The organic liquid fertilizer from each waste sample was placed in several containers and mixed with 5% phosphate buffer (as much as 20 mL), which was believed to produce the optimal conditions (Zulfarosda et al., 2022). The other storage conditions were a temperature of 8−10°C or 27−30°C, with or without direct sunlight exposure. The control conditions were no phosphate buffer and storage outside the refrigerator with direct sunlight exposure at 27°C−30°C (Table 1). Notably, X = refrigeration (8−10°C) and no exposure to sunlight, Y = no refrigeration (27−30°C) and no exposure to sunlight and Z = no refrigeration (27−30°C) and direct exposure to sunlight in Table 1 are variations in the storage conditions that were categorized as non-continuous (discrete) parameters and as such, there cannot be any simultaneous or interaction effects.

Table 1 Experimental variations investigated

Variable	Value
Food waste type	Mustard greens, Oranges, Pineapples, or Mangoes
Phosphate buffer	0 mL or 20 mL
Storage conditions	X: refrigeration (8–10°C) and no exposure to sunlight
	Y = no refrigeration (27–30°C) and no exposure to sunlight
	Z = no refrigeration (27–30°C) and direct exposure to sunlight

Statistical analysis

Statistical tests were conducted in two stages. Initially, a two-sample F-test for variances was conducted at a 95% confidence level to assess whether there were differences in variance between the two conditions. Based on the F-test results, a two-sample t-test was then performed. If the variances were significantly different ($p < 0.05$), a t-test assuming unequal variances was used; otherwise, a t-test assuming equal variances was applied. The final decision on the significance of the pH decrease between buffer addition and the storage conditions effects was determined using the t-test, with statistical significant set at $p < 0.05$.

Physicochemical and biological assay

pH and color

For all variations, the pH value of each tested fertilizer was measured in triplicate using a digital pH meter (ATC-2011, OEM Zhejiang)e. In addition, the product color was assessed using the ImageJ software (V 1.54, Softonic). This analysis investigated product blackening which was used to characterize any color change. The quantitative parameter of color changes was the gray value which was obtained graphically from the highest peak of the recorded results based on a scale of 0−255, where scale 0 indicates white and 255 indicates black. The greater the gray value obtained, the darker the color of the sample being measured.

Microbes

The microbial analysis considered *Acetobacter*, *Pseudomonas*, *Bacillus*, *Lactobacillus*, *Trichoderma*, nitrogen-fixing bacteria, phosphate-solubilizing bacteria, cellulolytic bacteria, chitinolytic bacteria, *Escherichia coli* and *Salmonella*. The microbes were grown on a specific agar medium and quantification was based on the plate counting method using a hemocytometer. For *Acetobacter*, 10 g of fertilizer sample was mixed in 90 mL of physiological salt solution and then diluted with variations of 1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL, 1×10^{-4} g/mL, 1×10^{-5} g/mL, 1×10^{-6} g/mL and 1×10^{-7} g/mL. Each variation was inoculated in an acetic acid bacteria selective medium at 30°C (Kim et al., 2019). The bacterial colonies were measured after incubation for 24 hr.

Based on the method of Suwito et al. (2019), the analysis of *Pseudomonas* bacteria began by adding 5 mL of sample to 25 mL of buffer peptone water. Various dilutions were made up (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL and 1×10^{-4} g/mL). A sample (1 mL) of each dilution was poured into an eosin methylene blue agar (EMBA) medium. Then, the bacteria were incubated at 37°C for 24 hr. Colonies growing in the EMBA medium were treated with Gram staining and a biochemical test was carried out subsequently to identify the bacteria.

Initially, the *Bacillus* bacteria were isolated. Up to 25 g of each sample was weighed aseptically using a sterile Erlenmeyer flask. Then, the sample was crushed and mixed with 0.9% NaCl. Next, the solution was diluted with various dilutions (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL and 1×10^{-4} g/mL). Each dilution was poured into a Petri dish containing Bacillus selective agar medium. Then, the solution was incubated for 24 hr at 37°C before analysis. *Lactobacillus* bacteria were isolated and cultured first before analysis. A total of 1 g of fertilizer sample was placed in a test tube containing 9 mL of distilled water. Then various dilutions (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL and 1×10^{-4} g/mL) were performed in Bacillus selective agar medium. Finally, the bacteria were incubated in the cup for 24−48 hr at 30°C.

The analysis of nitrogen-fixing bacteria began with isolation using the pour plate method. A sample of 10 g was dissolved in 90 mL of sterile distilled water and liquid Burk's medium (Singh et al., 2013) in an Erlenmeyer flask. Then, the sample was vortexed and diluted to various dilutions (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL and 1×10^{-4} g/mL). Up to 1,000 µL of each sample suspension from each dilution was added to a Petri dish containing Burk's medium (Singh et al., 2013). Bacterial observations were conducted daily for 5−7 d at 30−32°C. Bacteria that could fix nitrogen formed clear zones (Widawati and Suliasih, 2018).

Phosphate-solubilizing bacteria were isolated and cultured first. Up to 1 gram of fertilizer sample was dried at 105°C for 3 hr in an oven and then cooled in a desiccator. Various dilutions (1×10^{-2} g/mL, 1×10^{-3} g/mL, 1×10^{-4} g/mL, 1×10^{-5} g/mL and 1×10^{-10} g/mL) were made. Fungicide was added to each variation. Up to 1 mL of each dilution solution was poured into a Petri dish containing Pikovskaya agar medium. After that, each variation was shaken and incubated for 4−7 days at 30°C.

For cellulolytic bacteria, up to 25 g of fertilizer sample was placed in a test tube containing 250 mL of distilled water. Various dilutions (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL, 1×10^{-4} g/mL, 1×10^{-5} g/mL, 1×10^{-6} g/mL, 1×10^{-7} g/mL and 1×10^{-8} g/mL) were made. In total, 0.1 mL of each variation was inoculated on cellulose agar medium and incubated at 55°C for 48 hr (Dar et al., 2015; Arifin et al., 2019). In the meantime, a total of 5 g of chitinolytic bacteria samples were placed in a test tube containing 45 mL of physiological salt solution and vortexed evenly. Various dilutions (1×10^{-1} g/mL, 1×10^{-2} g/mL, 1×10^{-3} g/mL, 1×10^{-4} g/mL, 1×10^{-5} g/mL, 1×10^{-6} g/mL) were made. The dilute solutions were plated on chitin agar medium and incubated for 48 hr at 30°C. Colonies that grew formed a clear zone (Muharni and Widjajanti, 2011).

Up to 10 g samples of *Salmonella* and *Escherichia coli* bacteria were homogeneously mixed in separate test tubes containing distilled water. Each solution was diluted to either 1×10^{-1} g/mL or 1×10^{-2} g/mL. Then, 1 mL of each solution was poured into salmonella shigella agar medium for *Salmonella* bacteria and into EMBA medium for *Escherichia coli*. Each variation was incubated at 35°C for 24 hr.

The presence of *Salmonella* bacteria was indicated by a transparent color with a black spot in the middle, whereas *Escherichia coli* is shown by a metallic green color with a black spot in the middle (Fatiqin et al., 2019).

Amino acids

Analysis of the amino acid content in the product was based on high-performance liquid chromatography using a C18 column, the mobile phase in the form of ultra-aquabides acquisition tag eluent, a gradient pump system, a column temperature of 49°C and a photodiode array detector. The analysis procedure began with preparing amino acids standards in a 10 mL volumetric flask with a minimum of six different concentrations.

A sample (0.1 g) of each standard was placed in a 20 mL headspace vial and 4.2 mol/L NaOH solution was added. Next, the solution was hydrolyzed at 110°C for 20 hr. The hydrolyzed solution was transferred into a 50 mL beaker and citrate buffer was added. The solution was mixed with distilled water and then homogenized. Next, the sample solution was transferred into a 2 mL tube and centrifuged. The supernatant was passed through a 0.45 µm syringe filter and finally injected into the instrument.

Fatty acids

The fatty acids content in the product was recorded using gas chromatography-flame ionization detection with $NaOCH_3$ solvent in methanol. The results were presented in terms of concentrations of saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids and volatile fatty acids. The $NaOCH_3$-methanol method began with preparing a standard hexane solution at 1 concentration point. Samples were weighed equivalent to 50 mg of fat into a 20 mL screw-on vial. Subsequently, distilled water was added to the sample in solid form only. The transesterification solution was also added and the screw-on vial was closed for 10 s. Then, the vial was opened and hexane was added and then centrifuged. The organic phase was removed into a 2 mL vial and injected into the instrument.

Results and Discussion

Effects of food waste type on pH of organic liquid fertilizer

The highest pH in organic liquid fertilizer is advocated for mustard greens, followed by pineapples, mangoes and oranges, respectively (Fig. 2). The macronutrient content varied in every tested feedstock, as shown in Table 2. Mustard greens have the lowest content of carbohydrates and proteins, followed by oranges, pineapples and mangoes, respectively. The carbohydrates and proteins in food waste greatly influence the pH (Abidin et al., 2024a), with a lower carbohydrate content leading to a greater pH because fewer organic acids are formed during decomposition (Azara et al., 2021; Liu et al., 2021). On the other hand, lower protein contents result in fewer ammonium compounds that are formed through the deamination phase and are naturally basic (Jiang et al., 2015; Thakur et al., 2022).

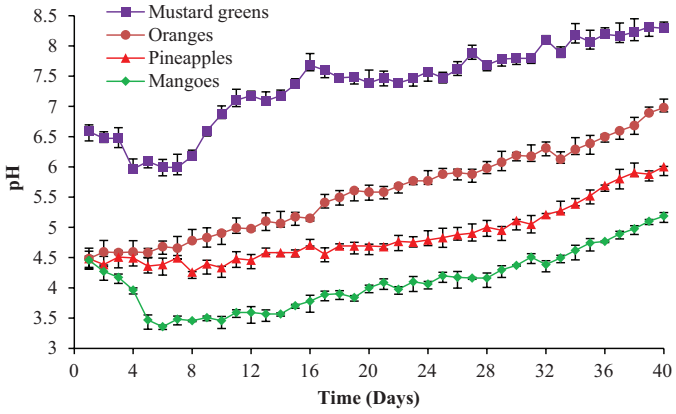

Fig. 2 pH profile of organic liquid fertilizer under several types of food waste, where error bars = standard deviation.

Table 2 Macronutrient content of several types of food waste (Evans et al., 2012; Azevedo et al., 2021).

Food waste type	Carbohydrate (%wt)	Protein (%wt)	Lipid (%wt)
Mustard greens	9.00	0.12	0.10
Oranges	21.15	0.54	0.12
Pineapples	22.95	0.94	0.12
Mangoes	28.70	1.28	0.38

wt = weight

Effects of 5% phosphate buffer on pH and color of organic liquid fertilizer

Phosphate buffer acts as a solution to maintain the pH in the desired and optimal range which implicitly has an impact on the fertilizer quality. Furthermore, adding phosphate buffer can alter the pH and color of the product. The pH profile of each tested food waste type is presented in Fig. 3. Adding 20 mL of 5% phosphate buffer, decreased the pH of the organic liquid fertilizer made from mango, pineapple, mustard greens and orange wastes to 3.0, 3.3, 4.1 and 3.8, respectively.

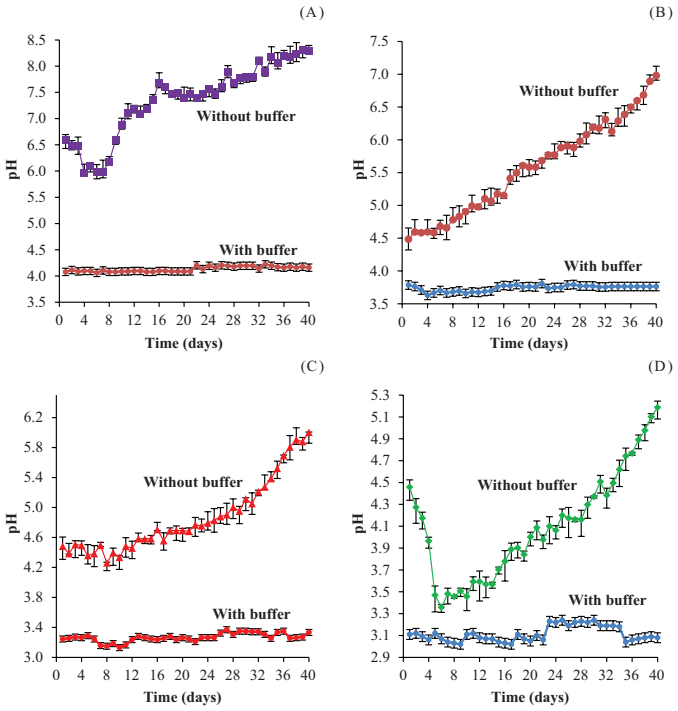

Fig. 3 pH profile of organic liquid fertilizer with addition of 20 mL of 5% phosphate buffer to waste from: (A) mangoes; (B) pineapples; (C) mustard greens; and (D) oranges, where error bars = standard deviation.

The addition of phosphate buffer to all types of food waste significantly decreased the pH, as indicated by the t stat values being far greater than the t critical left-tail, presented in Table 3. Based on the pH profile and statistical analysis, the phosphate buffer was successful in reducing and maintaining the pH solution at 3−4 with negligible changes in dynamics.

In addition, the gray value for organic liquid fertilizer from mustard greens after 40 d changed from 126 to 139 (Figs. 4A and 4B) while for the fertilizer made from orange waste changed from 113 to 128 (Figs. 4C and 4D). These increases indicated that the product color became blacker after the phosphate buffer addition. This was consistent with the study by Wang et al. (2018), in which the anaerobic fermentation of food waste over time blackened the product color due to ammonification (deamination) activity. This action was also proven visually by Abidin et al. (2024a).

However, after 40 d, there was a slowdown in the blackening of the fertilizer as indicated by a change in the gray value which only increased from 172 to 176 (Figs. 4E and 4F) for mustard greens from 170 to 171 for the fertilizer made from orange waste (Figs. 4G and 4H). Thus, phosphate buffers extend the product's shelf life.

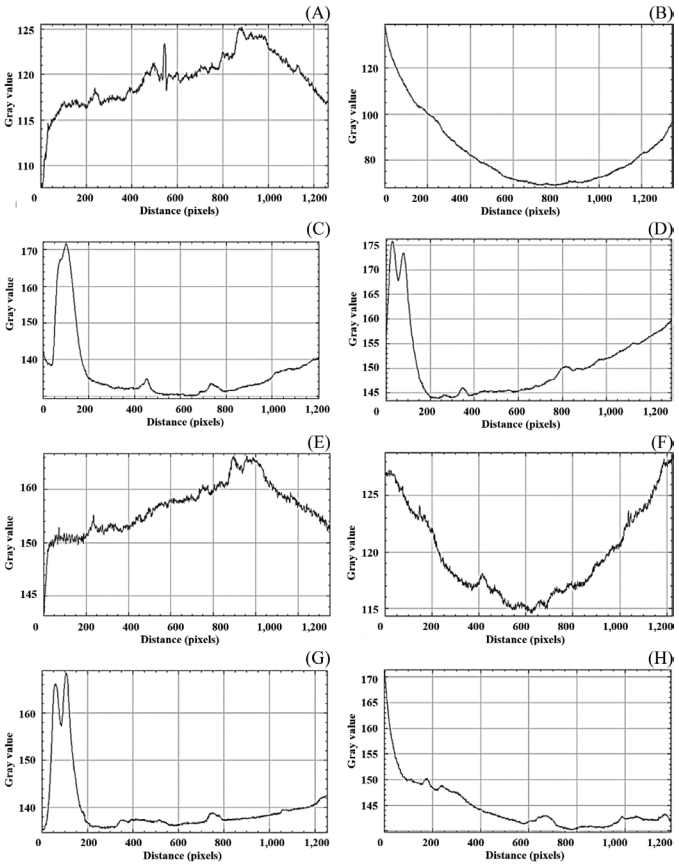

Fig. 4 Gray value of organic liquid fertilizer made from waste from: (A) mustard greens before buffer addition; (B) mustard greens before buffer addition after 40 d; (C) mustard greens after buffer addition; (D) mustard greens after buffer addition after 40 d; (E) oranges before buffer addition; (F) oranges before buffer addition after 40 d; (G) oranges after buffer addition; (H) oranges after buffer addition after 40 d.

Table 3 Results of statistical analysis of the pH of various food waste samples with and without phosphate buffer addition.

Parameter	Mustard greens		Oranges		Pineapples		Mangoes	
	No buffer	Buffer	No Buffer	Buffer	No buffer	Buffer	No buffer	Buffer
Mean	7.35	4.13	5.57	3.74	4.86	3.27	4.11	3.11
Variance	0.49	0.00	0.52	0.00	0.23	0.00	0.24	0.01
F	198.05		262.29		70.41		48.33	
p value (F test, two-tail)	0.00		0.00		0.00		0.00	
t stat (unequal variances)	65.61		16.02		20.83		12.64	
p value (t test, left-tail)	0.00		0.00		0.00		0.00	

Effects of 5% phosphate buffer on microbial content in organic liquid fertilizer

Table 4 shows that *Pseudomonas*, *Lactobacillus*, *Trichoderma*, cellulolytic bacteria and chitinolytic bacteria were present after adding the phosphate buffer. This has a positive impact on the organic liquid fertilizer content because these bacteria secrete substances that support plant growth. For example, *Pseudomonas* bacteria produce protease, lipase, cellulase and amylase enzymes and can trigger plant growth as biostimulants and prevent growth by pathogens (Widnyana and Javandira, 2016). *Trichoderma* fungi stimulate plant growth, augment plant tolerance to abiotic stress and prevent plant diseases caused by pathogens (Poveda and Eugui, 2022). *Lactobacillus* bacteria can produce antimicrobial compounds such as lactic acid, acetic acid, probiotics, antibiotics and bacteriocins (De et al., 2018). Cellulolytic bacteria decompose organic substances into nutrients needed by plants (Hapsoh et al., 2019), while chitinolytic bacteria act as inhibitors to the pathogenic growth (Gohel et al., 2016).

The increase in the number of microbes after adding the phosphate buffer confirmed that the phosphate buffer had a positive effect on fertilizer quality. This was reinforced by the decreases in the pathogens in the fertilizer, namely *Escherichia coli* and *Salmonella*. Other microbes declined following the addition of the phosphate buffer but were still above the quality standard threshold, except for *Bacillus*. This could have been due to the phosphate buffer slowing down and even inhibiting the fertilizer fermentation process in the deamination phase. *Bacillus* consumes amino acids and converts them into ammonium (Poveda and Eugui, 2022). Consequently, the reduced level of amino acids could have resulted in a decreasing amount of *Bacillus* bacteria in the organic liquid fertilizer.

The microbes in the fertilizers were not pathogenic as they were in the liquid and could not readily become airborne, thus complying with biosafety considerations for users. Furthermore, while *Escherichia coli* and *Salmonella* are foodborne pathogenic bacteria (Tran et al., 2020) their concentrations were far below the standard in the fertilizer. In fact, the recruitment of microbes is needed in the soil to prevent plant disease from pathogens (Huang et al., 2019). Paśmionka et al. (2021) reported that nitrogen-fixing bacteria provide plant protection properties from phytopathogens. Cheng et al. (2023) also found that phosphate-solubilizing bacteria act against phytopathogens and fungal pathogens in plants, while *Pseudomonas*, *Bacillus* and *Trichoderma* can act as plant pathogen suppressors (Tao et al., 2020; Poveda and Eugui, 2022).

Effects of 5% phosphate buffer on organic acids content in organic liquid fertilizer

Fermentation converts biopolymeric compounds in the food waste into more soluble monomeric compounds. Fats and proteins are hydrolyzed into fatty acids and amino acids, with the amino acids then being utilized for protein synthesis and plant growth regulation and development, especially under stress conditions (Trovato et al., 2021). Fatty acids, especially unsaturated fatty acids, act as structural components in membranes, providing energy for metabolic processes and participating in protecting plants from biotic and abiotic stress (Kalinger et al., 2018; Cahoon and Li-Beisson, 2020). The amino acids and fatty acids in the organic liquid fertilizer made from orange waste before and after adding phosphate buffer are shown in Table 5.

Table 4 Microbial content in organic liquid fertilizer from orange waste before and after adding phosphate buffer.

Microbe	Unit	Standard	Without phosphate buffer	With phosphate buffer
Acetobacter	CFU/mL	$\geq 1 \times 10^5$	1.20×10^9	6.11×10^7
Pseudomonas	CFU/mL	$\geq 1 \times 10^5$	8.77×10^8	5.54×10^9
Bacillus	CFU/mL	$\geq 1 \times 10^5$	1.55×10^7	1.00×10^4
Lactobacillus	CFU/mL	$\geq 1 \times 10^5$	1.85×10^7	2.50×10^9
Trichoderma	CFU/mL	$\geq 1 \times 10^5$	<10	2.58×10^6
Nitrogen fixing bacteria	CFU/mL	$\geq 1 \times 10^5$	6.11×10^8	3.89×10^7
Phosphate solubilizing bacteria	CFU/mL	$\geq 1 \times 10^5$	6.42×10^8	3.22×10^7
Cellulolytic bacteria	CFU/mL	$\geq 1 \times 10^5$	1.55×10^7	9.08×10^8
Chitinolytic bacteria	CFU/mL	$\geq 1 \times 10^5$	2.40×10^5	1.00×10^7
Escherichia coli	MPN/mL	$<1 \times 10^2$	<3	<3
Salmonella	MPN/mL	$<1 \times 10^2$	3.6	<3

Table 5 Amino acids and fatty acids content in organic liquid fertilizer from orange waste before and after adding phosphate buffer.

Compound	Unit	Before phosphate buffer addition	After phosphate buffer addition
L-Alanine	mg/kg	<84.63	<84.63
Glysine	mg/kg	194.89	213.67
L-Methionine	mg/kg	0.71	1.51
Palmitic acid	mg/kg	286.5	268.5
Stearic acid	mg/kg	104.5	948.5
Oleic acid	mg/kg	300.5	394.0
Linoleic acid	mg/kg	104.5	268.5

mg/kg (parts per million)

Based on these results, the alanine content before and after buffer addition was nearly the same. In addition, there was an increase in the glycine content from 194.89 mg/kg to 213.67 mg/kg after adding the phosphate buffer. In contrast, there was an increase in the L-methionine content from 0.71 mg/kg before adding the phosphate buffer to 1.51 mg/kg after adding the buffer. Phosphorus-based compounds are essential biogenic elements that play a role in amino acid metabolism, thereby providing a synergistic influence on plant growth (Cheng et al., 2023).

The escalation in the fatty acids content after adding the phosphate buffer was caused by the amino acids formed being utilized by the existing microbes as a food source for reproduction so that the high growth of bacteria and decomposition resulting from organic material increased the availability of nutrients (including fatty acids) in the fermentation process (Herawati et al., 2018). In summary, the addition of the phosphate buffer enriched the amino acids and fatty acids in the organic liquid fertilizer.

Effects of storage conditions on pH and color in organic liquid fertilizer

The pH profiles of the organic liquid fertilizers without phosphate buffer during storage are presented in Fig. 5. It can be seen that storage in the refrigerator (8−10°C, condition X) resulted in a decreasing pH trend until day 40 since low temperatures inhibit the further oxidation of the product and actually preserve it. In contrast, storage at room temperature (27−30°C, conditions Y and Z) without or with direct sunlight exposure resulted in an escalating pH trend until day 40.

There were significant changes in fertilizer pH caused by the increasing storage temperature (Y versus X) and direct exposure to sunlight (Z versus Y), as shown in Table 6.

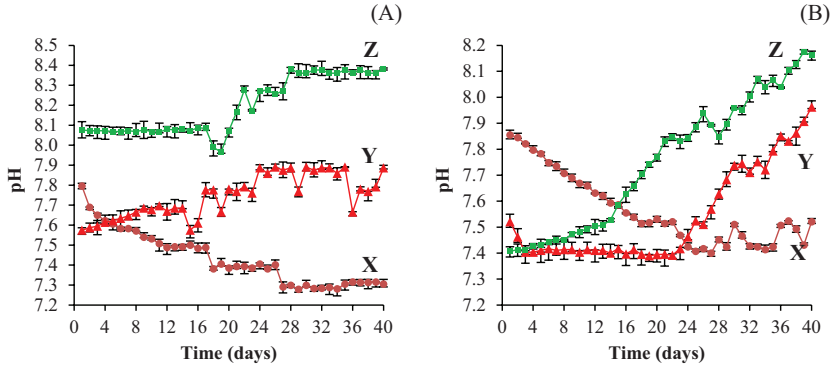

Fig. 5 pH profile of organic liquid fertilizer made of waste from: (A) mustard greens; (B) oranges under storage conditions X, Y, and Z, where X = refrigeration (8-10°C) and no exposure to sunlight, Y = no refrigeration (27-30°C) and no exposure to sunlight and Z = no refrigeration (27-30°C) and direct exposure to sunlight, where error bars = standard deviation.

Table 6 Results of statistical analysis of the pH of food waste samples after 40 d without phosphate buffer, kept in various storage conditions.

Parameter	Mustard greens				Oranges			
	Y	X	Z	Y	Y	X	Z	Y
Mean	7.75	7.43	8.19	7.75	7.53	7.59	7.75	7.53
Variance	0.01	0.02	0.02	0.01	0.04	0.01	0.06	0.04
F	1.53		1.72		2.43		1.78	
p value (F-test, two-tail)	0.09		0.05		0.00		0.05	
t stat	11.58*		15.87*		2.57†		4.30*	
p value (t-test, left-tail)	0.00		0.00		0.01		0.00	

X = refrigeration (8–10°C) and no exposure to sunlight, Y = no refrigeration (27–30°C) and no exposure to sunlight, and Z = no refrigeration (27–30°C) and direct exposure to sunlight;

* = equal variances; † = unequal variances.

Higher temperatures accelerate fertilizer deterioration, which when coupled with sunlight exposure triggers photo-oxidations (Conte et al., 2021), resulting in the carbohydrates being further oxidized into organic acids, while fats are oxidized into rancid compounds (Moraes et al., 2014) and amino acids are increasingly deaminated into ammonia (Hildebrandt et al., 2015). Thus, overall, the levels of organic acids were lowered, the ammonium content was increased and the pH increased.

The gray value of organic liquid fertilizer from mustard greens stored in the refrigerator reduced after 40 d from 130 to 110 (Figs. 6A and 6B), compared to outdoor storage with exposure to sunlight for 40 d resulting in an increase from 86 to 98 (Figs. 6C and 6D) and from 118 to 128 (Figs. 6E and 6F). In accordance with the color analysis, sunlight exposure and room temperature induced product blackening. This phenomenon is actually an indicator of the ammonium formation in fertilizer due to deamination as reported Abidin et al. (2024d) and also reinforced by other studies (Wang et al., 2018; Lawal et al., 2023).

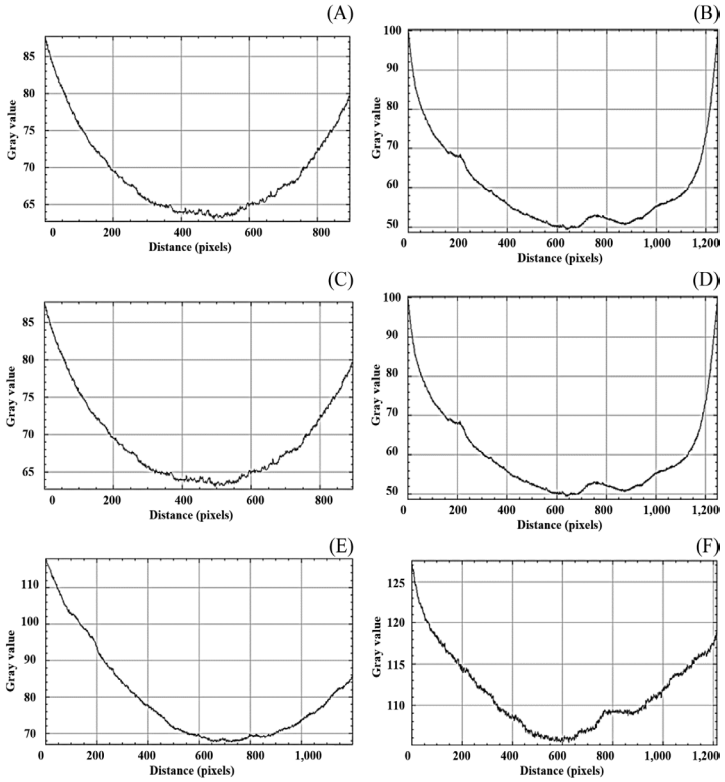

Fig. 6 Gray value of organic liquid fertilizer from mustard greens at (A) condition X; (B) condition X after 40 d; (C) condition Y; (D) condition Y after 40 d; (E) condition Z; and (F) condition Z after 40 d, where X = refrigeration (8–10°C) and no exposure to sunlight, Y = no refrigeration (27–30°C) and no exposure to sunlight and Z = no refrigeration (27–30°C) and direct exposure to sunlight.

Nevertheless, the deamination stage itself should occur when the fertilizer is applied in the soil and to the plant, not in the packaging (Paśmionka et al., 2021). Therefore, storage at low temperatures and without direct sunlight exposure is not recommended.

Conclusions

The study successfully investigated extending the shelf life of organic liquid fertilizer from food waste fermentation using Masaro technology. Greater carbohydrate and protein contents in food waste lowered the pH. Furthermore, the addition of phosphate buffer maintained the pH and slowed down product blackening, maintaining the nutrients and growth-supporting bacteria contained in the liquid fertilizer. Furthermore, higher temperatures and direct sunlight exposure increased the pH and darkened the color. Therefore, the recommended storage conditions for the organic liquid fertilizer are refrigeration at 8C−10°C without direct sunlight exposure. Finally, this study helped to facilitate food waste management through the production of organic liquid fertilizer, resulting in more economical prices and reduced carbon emissions caused by both disposing of organic waste and synthetic fertilizer production. These findings could support national agricultural productivity, the reduction of fertilizer subsidy costs and reduced government costs in waste management.

Conflict of Interest

The authors declare that there are no conflicts of interest associated with this publication.

Acknowledgments

MASARO Jabar Lestari, Inc. provided the research facilities and equipment. Dr Soen Steven was supported by the Postdoctoral Scheme at the Research Center for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency (BRIN), Indonesia 2024−2025.

References

Abidin, A.Z., Bramantyo, H., Baroroh, M.K., Egiyawati, C. 2021a. Circular economy on organic waste management with MASARO technology. IOP Conf. Ser. Mater. Sci. Eng. 1143: 012051. doi.org/10.1088/1757-899X/1143/1/012051

Abidin, A.Z., Steven, S., Fadli, R., Nabiel, M.F., Yemensia, E.V., Soekotjo, E.S.A., Rahman Setiawan, A.A., Sasongko, N.A., Rendra Graha, H.P., Abidin, T., Putra, R.P. 2024a. Influence of several physical parameters in enzymatic fermentation of vegetable and fruit waste to produce organic liquid fertilizer using MASARO technology. Results Eng. 23: 102567. doi.org/10.1016/j.rineng.2024.102567

Abidin, A.Z., Steven, S., Rambe, S., Matin, A., Yemensia, E.V., Sari, D.A., Putra, R.P. 2024b. Application of special liquid fertilizer from organic wastes to promote growth and productivity of red chilli plants (*Capsicum annuum* L.). J. Teknol. 86: 79–90. doi.org/10.11113/jurnalteknologi.v86.21200

Abidin, A.Z., Steven, S., Sirait, A.S., Sianturi, B.N.B., Yemensia, E.V., Suyadi, M.M.A., Soekotjo, E.S.A., Matin, A., Putra, R.P. 2024c. Comparative analysis of waste management between MASARO and refuse-derived fuel (RDF) technologies in West Java. E3S Web Conf. 519: 04004. doi.org/10.1051/e3sconf/202451904004

Abidin, A.Z., Steven, S., Siregar, N.S., Hutahaean, A.C., Yemensia, E.V., Otivriyanti, G., Wardani, M.L.D., Mulyono, M., Soekotjo, E.S.A., Sasongko, N.A., Djamal, M. 2024d. Influences of pH control in the organic liquid fertilizer production using MASARO technology. IOP Conf. Ser. Earth Environ. Sci. 1344: 012022. doi.org/10.1088/1755-1315/1344/1/012022

Abidin, A.Z., Yemensia, E.V., Wijaya, K.W., Rahardjo, A.P. 2021b. Circular economy on non-biodegradable waste management with MASARO technology. IOP Conf. Ser. Mater. Sci. Eng. 1143: 012052. doi.org/10.1088/1757-899X/1143/1/012052

Al-khadher, S.A.A., Abdul Kadir, A., Al-Gheethi, A.A.S., Azhari, N.W. 2021. Takakura composting method for food wastes from small and medium industries with indigenous compost. Environ. Sci. Pollut. Res. 28: 65513–65524. doi.org/10.1007/s11356-021-15011-0

Arifin, Z., Gunam, I.B.W., Antara, N.S., Setiyo, Y. 2019. Isolasi bakteri selulolitik pendegradasi selulosa dari kompos. J. rekayasa manaj. agroindustri. 7: 30. doi.org/10.24843/JRMA.2019.v07.i01.p04 [in Indonesian]

Azara, R., Qur'aini, L., Saidi, I.A., Hudi, L., Nurbaya, S.R., Budiandari, R.U. 2021. Quality of fermented purple sweet potato (*Ipomea batatas* var. *Ayamurasaki*) (tapai) in various yeast concentration and steaming time. IOP Conf. Ser. Earth Environ. Sci. 819: 012052. doi.org/10.1088/1755-1315/819/1/012052

Azevedo, A., Gominho, J., Duarte, E. 2021. Performance of anaerobic co-digestion of pig slurry with pineapple (*Ananas comosus*) bio-waste residues. Waste Biomass Valor. 12: 303–311. doi.org/10.1007/s12649-020-00959-w

Cahoon, E.B., Li-Beisson, Y. 2020. Plant unusual fatty acids: learning from the less common. Curr. Opin. Plant Biol. 55: 66–73. doi.org/10.1016/j.pbi.2020.03.007

Cheng, Y., Narayanan, M., Shi, X., Chen, X., Li, Z., Ma, Y. 2023. Phosphate-solubilizing bacteria: Their agroecological function and optimistic application for enhancing agro-productivity. Sci. Total Environ. 901: 166468. doi.org/10.1016/j.scitotenv.2023.166468

Conte, F., Pellegatta, V., Tripodi, A., Ramis, G., Rossetti, I. 2021. Photo-Oxidation of ammonia to molecular nitrogen in water under uv, vis and sunlight irradiation. Catalysts. 11: 975. doi.org/10.3390/catal11080975

Dar, M.A., Pawar, K.D., Jadhav, J.P., Pandit, R.S. 2015. Isolation of cellulolytic bacteria from the gastro-intestinal tract of *Achatina fulica* (Gastropoda: Pulmonata) and their evaluation for cellulose biodegradation. Int. Biodeterior. Biodegradation. 98: 73–80. doi.org/10.1016/j.ibiod.2014.11.016

De, S., Pramanik, A., Das, A.K., Paul, S., Bera, M.K. 2018. Study the effects of seed germination and plant growth promoting activity of *Lactobacillus* sp. Int. J. Res. Pharm. Pharm. Sci. 3: 1–3.

Evans, P.J., Nelsen, D.A., Amador, J.C., Mcpherson, C., Parry, D.L., Stensel, H.D. 2012. Energy recovery from food waste via anaerobic digestion, In: Proceedings of World Congress on Water, Climate and Energy. Dublin, Ireland. pp. 1–4.

Fatiqin, A., Novita, R., Apriani, I. 2019. Pengujian *Salmonella* dengan menggunakan media SSA dan *E. coli* menggunakan media EMBA pada bahan pangan. Indobiosains 1: 1–8. doi.org/10.31851/indobiosains.v1i1.2206 [in Indonesian]

Febijanto, I., Steven, S., Nadirah, N., Bahua, H., Shoiful, A., Dewanti, D.P., Kristyawan, I.P.A., Haris, K.A., Yuliani, M., Hanif, M., Robbani, M.H., Yusuf, N.R., Prihartanto, Alfatri, P., Pratama, R.A., Purwanta, W., Wiharja, Nugroho, R., Ramadhan, S.K. 2024. Municipal Solid Waste (MSW) reduction through incineration for electricity purposes and its environmental performance: A case study in Bantargebang, West Java, Indonesia. Evergreen. 11: 32–45. doi.org/10.5109/7172186

Gohel, V., Singh, A., Vimal, M., Ashwini, P., Chhatpar, H.S. 2016. Bioprospecting and antifungal potential of chitinolytic microorganisms. African J. Biotechnol. 5: 1–19.

Hapsoh, Dini, I.R., Salbiah, D., Kusmiati, D. 2019. Growth and pepper yields (*Capsicum annuum* L.) by giving a formulation of biological fertilizer of cellulolytic bacteria based on organic liquid waste. J. Phys. Conf. Ser. 1351: 012097. doi.org/10.1088/1742-6596/1351/1/012097

Hartman, G.L., Pawlowski, M.L., Chang, H.X., Hill, C.B. 2016. Successful technologies and approaches used to develop and manage resistance against crop diseases and pests, In: Emerging technologies for promoting food security. Woodhead Publishing, Elsevier. Amsterdam, the Netherlands, pp. 43–66. doi.org/10.1016/B978-1-78242-335-5.00003-2

Herawati, V.E., Nugroho, R.A., Pinandoyo, Darmanto, Y.S., Hutabarat, J. 2018. The effect of fermentation time with probiotic bacteria on organic fertilizer as daphnia magna cultured medium towards nutrient quality, biomass production and growth performance enhancement. IOP Conf. Ser. Earth Environ. Sci. 116: 012089. doi.org/10.1088/1755-1315/116/1/012089

Hildebrandt, T.M., Nunes Nesi, A., Araújo, W.L., Braun, H.P. 2015. Amino acid catabolism in plants. Mol. Plant 8: 1563–1579. doi.org/10.1016/j.molp.2015.09.005

Huang, R., McGrath, S.P., Hirsch, P.R., Clark, I.M., Storkey, J., Wu, L., Zhou, J., Liang, Y. 2019. Plant-microbe networks in soil are weakened by century-long use of inorganic fertilizers. Microb. Biotechnol. 12: 1464–1475. doi.org/10.1111/1751-7915.13487

Iravanian, A., Ravari, S.O. 2020. Types of contamination in landfills and effects on the environment: A review study. IOP Conf. Ser. Earth Environ. Sci. 614: 012083. doi.org/10.1088/1755-1315/614/1/012083

Jiang, Y., Ju, M., Li, W., Ren, Q., Liu, L., Chen, Y., Yang, Q., Hou, Q., Liu, Y. 2015. Rapid production of organic fertilizer by dynamic high-temperature aerobic fermentation (DHAF) of food waste. Bioresour. Technol. 197: 7–14. doi.org/10.1016/j.biortech.2015.08.053

Kalinger, R.S., Pulsifer, I.P., Rowland, O. 2018. Elucidating the substrate specificities of acyl-lipid thioesterases from diverse plant taxa. Plant Physiol. Biochem. 127: 104–118. doi.org/10.1016/j.plaphy.2018.03.013

KemenLHK. 2023. Ministry of Environment and Forestry (Kementrian Lingkungan Hidup dan Kehutanan). Municipal waste composition in Indonesia. https://www.menlhk.go.id/, 16 September 2024.

Kim, D.H., Chon, J.W., Kim, H., Seo, K.H. 2019. Development of a novel selective medium for the isolation and enumeration of acetic acid bacteria from various foods. Food Control. 106: 106717. doi.org/10.1016/j.foodcont.2019.106717

Lawal, I.M., Soja, U.B., Hussaini, A., Saleh, D., Aliyu, M., Noor, A., Birniwa, A.H., Jagaba, A.H. 2023. Sequential batch reactors for aerobic and anaerobic dye removal: A mini-review. Case Stud. Chem. Environ. Eng. 8: 100547. doi.org/10.1016/j.cscee.2023.100547

Liu, Y., Li, X., Wu, S., Tan, Z., Yang, C. 2021. Enhancing anaerobic digestion process with addition of conductive materials. Chemosphere. 278: 130449. doi.org/10.1016/j.chemosphere.2021.130449

Moraes, C.A., Fernandes, I.J., Calheiro, D., Kieling, A.G., Brehm, F.A., Rigon, M.R., Berwanger Filho, J.A., Schneider, I.A., Osorio, E. 2014. Review of the rice production cycle: By-products and the main applications focusing on rice husk combustion and ash recycling. Waste Manag. Res. 32: 1034–1048. doi.org/10.1177/0734242X14557379

Muharni, M., Widjajanti, H. 2011. Skrining bakteri kitinolitik antagonis terhadap pertumbuhan jamur akar putih (*Rigidoporus lignosus*) dari rizosfir tanaman karet. J. Penelit. Sains. 14: 51–56 [in Indonesian]

Nugroho, R.A., Rofiq, M.N., Santoso, A.D., Yanuar, A.I., Hanifa, R., Nadirah, N. 2023. Bioconversion of biowaste by black soldier fly larvae (*Hermetia illucens* L.) for dried larvae production: A life cycle assessment and environmental impact analysis. F1000Research 12: 814. doi.org/10.12688/f1000research.132371.1

Paśmionka, I.B., Bulski, K., Boligłowa, E. 2021. The participation of microbiota in the transformation of nitrogen compounds in the soil—A review. Agronomy. 11: 977. doi.org/10.3390/agronomy11050977

Poveda, J., Eugui, D. 2022. Combined use of Trichoderma and beneficial bacteria (mainly Bacillus and Pseudomonas): Development of microbial synergistic bio-inoculants in sustainable agriculture. Biol. Control 176: 105100. doi.org/10.1016/j.biocontrol.2022.105100

Satinder, K.B. 2012. Shelf-life of Biofertilizers: An accord between formulations and genetics. J Biofertil. Biopestici. 3:1000e109. doi.org/10.4172/2155-6202.1000e109

Singh, R.K.S., Mazumder, P.B., Bhattacharjee, M.K., Sharma, G.D. 2013. Determination of nitrogen fixing capacity of bacteria isolated from the rhizosphere soil of *Crotolaria pallida* from the valley districts of Manipur, India. IOSR J. Pharm. Biol. Sci. 8: 20–24.

Stella, M., Theeba, M., Illani, Z.I. 2019. Organic fertilizer amended with immobilized bacterial cells for extended shelf-life. Biocatal. Agric. Biotechnol. 20: 101248. doi.org/10.1016/j.bcab.2019.101248

Steven, S., Dwiputra, G.A., Affan, M.K.A., Soekotjo, E.S.A., Syamsudin, E., Nadirah, N., Sasongko, N.A., Yemensia, E.V., Abidin, A.Z. 2024. Combination of waste processing between MASARO plastic refinery unit and maggots technology. IOP Conf. Ser. Earth Environ. Sci. 1344: 012023. doi.org/10.1088/1755-1315/1344/1/012023

Suwito, W., Andriani, A., Nugroho, W.S. 2019. Isolasi dan identifikasi bakteri dari susu kambing peranakan Ettawa (PE) terjangkit mastitis subklinis di Kemiri Kebo, Sleman, Yogyakarta. J. Ilmu-Ilmu Peternak. 29: 56–64. doi.org/10.21776/ub.jiip.2019.029.01.07 [in Indonesian]

Tao, C., Li, R., Xiong, W., Shen, Z., Liu, S., Wang, B., Ruan, Y., Geisen, S., Shen, Q., Kowalchuk, G.A. 2020. Bio-organic fertilizers stimulate indigenous soil *Pseudomonas* populations to enhance plant disease suppression. Microbiome. 8: 137. doi.org/10.1186/s40168-020-00892-z

Thakur, H., Dhar, A., Powar, S. 2022. Biogas production from anaerobic co-digestion of sewage sludge and food waste in continuously stirred tank reactor. Results Eng. 16: 100617. doi.org/10.1016/j.rineng.2022.100617

Tran, D.T.Q., Bradbury, M.I., Ogtrop, F.F.V., Bozkurt, H., Jones, B.J., Mcconchie, R. 2020. Environmental Drivers for Persistence of *Escherichia coli* and *Salmonella* in manure-amended soils: A meta-analysis. J. Food Prot. 83: 1268–1277. doi.org/10.4315/0362-028X.JFP-19-460

Trovato, M., Funck, D., Forlani, G., Okumoto, S., Amir, R. 2021. Editorial: Amino acids in plants: Regulation and functions in development and stress defense. Front. Plant Sci. 12: 772810. doi.org/10.3389/fpls.2021.772810

Wang, C., Wang, N., Zhu, J., Liu, Y., Xu, X., Niu, S., Yu, G., Han, X., He, N. 2018. Soil gross N ammonification and nitrification from tropical to temperate forests in eastern China. Funct. Ecol. 32: 83–94. doi.org/10.1111/1365-2435.13024

Widawati, S., Suliasih. 2018. The effect of plant growth promoting rhizobacteria (PGPR) on germination and seedling growth of Sorghum bicolor L. Moench. IOP Conf. Ser. Earth Environ. Sci. 166: 012022. doi.org/10.1088/1755-1315/166/1/012022

Widnyana, I.K., Javandira, C. 2016. Activities *Pseudomonas* spp. and *Bacillus* sp. to stimulate germination and seedling growth of tomato plants. Agric. Agric. Sci. Procedia. 9: 419–423. doi.org/10.1016/j.aaspro.2016.02.158

Yemensia, E.V., Steven, S., Soekotjo, E.S.A., Abidin, A.Z. 2023. Prospect and application of flue gas washing liquid from wet scrubber unit at Masaro plastic refinery for organic pesticides. IOP Conf. Ser. Earth Environ. Sci. 1268: 012040. doi.org/10.1088/1755-1315/1268/1/012040

Zhu, J., Luo, Z., Sun, T., Li, W., Zhou, W., Wang, X., Fei, X., Tong, H., Yin, K. 2023. Cradle-to-grave emissions from food loss and waste represent half of total greenhouse gas emissions from food systems. Nat. Food 4: 247–256. doi.org/10.1038/s43016-023-00710-3

Zulfarosda, R., Purnamasari, R.T., Julaikha, S. 2022. Pengaruh variasi kelat pupuk mikro fe terhadap ph larutan nutrisi dan berat tanaman selada (*Lactuca sativa* L.) pada sistem hidroponik. J. Ilm. Ilmu Cendekia. 1: 12–17. doi.org/10.32503/hijau.v5i1.683 [in Indonesian]