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Valorization of Food Processing Cake Waste into Organic Fertilizer Using a Double-Molasses Biofermentation System

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ABSTRACT

The increasing generation of agro-industrial food processing waste presents environmental challenges while offering opportunities for resource recovery within a circular bioeconomy. This study evaluated the conversion of food processing cake waste from PT Belfoods Indonesia (Nganjuk, Indonesia) into organic fertilizer using a double-molasses biofermentation system with beneficial microorganisms activated by fresh sugarcane juice and palm sugar. A longitudinal experimental approach was applied through three stages: raw material characterization, biofermentation, and mature fertilizer production. Physicochemical properties were analyzed using standardized laboratory methods, while fertilizer performance was assessed through a 14-day field bioassay. Biofermentation significantly improved fertilizer quality, increasing total nitrogen from 0.17% to 0.69% and available phosphorus (P_2O_5) from 60.47 mg kg^{-1} to 5,264.77 mg kg^{-1}. The final product contained no detectable hazardous heavy metals, including arsenic, cadmium, mercury, lead, and tin, confirming its environmental safety. Field observations showed improved plant growth, characterized by darker green leaves, greater foliage density, and stronger stems after fertilizer application. These findings demonstrate that the proposed double-molasses biofermentation system effectively transforms food processing cake waste into a safe, nutrient-enriched organic fertilizer with promising agronomic potential, supporting sustainable waste valorization and circular agricultural production.

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1. INTRODUCTION

The rapid expansion of the food processing industry has significantly increased the generation of organic solid waste worldwide. Food processing residues are rich in biodegradable organic matter, including carbohydrates, proteins, and lipids, making them valuable feedstocks for resource recovery rather than disposal. However, improper management of these residues can cause severe environmental problems, including greenhouse gas emissions, odor pollution, pathogen proliferation, and leachate contamination of soil and water resources (FAO, 2019). Consequently, the transition from a linear waste-disposal model toward a circular bioeconomy has become an important strategy for improving environmental sustainability while creating additional economic value from agro-industrial residues (European Commission, 2018)).

Waste valorization has emerged as one of the most promising approaches for transforming organic industrial residues into value-added products such as bioenergy, biochar, compost, organic fertilizers, and other bio-based materials (Lin et al., 2022). Among these alternatives, the production of organic fertilizer is particularly attractive because it simultaneously addresses waste management challenges and improves soil fertility through nutrient recycling. Organic fertilizers contribute to soil organic matter accumulation, improve soil structure, stimulate beneficial microbial activity, and reduce dependence on synthetic fertilizers, thereby supporting sustainable agricultural production (Agegnehu et al., 2017).

Indonesia's food processing sector continues to grow rapidly, generating substantial quantities of biodegradable solid waste. PT Belfoods Indonesia, one of the major frozen food manufacturers located in Nganjuk, East Java, produces considerable amounts of food processing cake waste as a by-product of its manufacturing operations. This residue contains abundant biodegradable organic compounds, suggesting considerable potential for conversion into organic fertilizer through controlled biological processes. Nevertheless, if disposed of without proper treatment, the waste may contribute to environmental pollution due to its high organic loading and rapid microbial decomposition (Kaza et al., 2018).

Biological fermentation has become one of the most environmentally friendly technologies for converting organic waste into stable and nutrient-rich fertilizer. During biofermentation, microorganisms degrade complex organic compounds into simpler molecules while mineralizing essential plant nutrients such as nitrogen, phosphorus, and potassium. The efficiency of this process largely depends on microbial activity, which is strongly influenced by the availability of readily metabolizable carbon sources (Bernal et al., 2009). Therefore, providing sufficient carbon substrates during fermentation is essential for accelerating microbial growth and enhancing nutrient transformation.

Molasses has long been recognized as an effective carbon source for microbial fermentation because of its high sugar content and its ability to stimulate microbial metabolism. In this study, a double-molasses biofermentation system, consisting of fresh sugarcane juice and palm sugar, was developed to enhance microbial activity during the fermentation of food processing cake waste. Fresh sugarcane juice supplies readily available glucose, vitamins, minerals, and moisture, whereas palm sugar provides concentrated sucrose and additional organic compounds that support prolonged microbial metabolism. The combination of these two natural carbon sources is expected to create a more stable fermentation environment than conventional single-molasses systems, thereby accelerating organic matter decomposition and nutrient mineralization.

Among essential plant nutrients, phosphorus plays a critical role in energy transfer, root development, flowering, and overall crop productivity. However, phosphorus in organic residues is frequently present in insoluble forms that cannot be directly absorbed by plants. During microbial fermentation, organic acids produced by beneficial microorganisms can solubilize bound phosphorus into plant-available forms, thereby increasing fertilizer quality (Sharma et al., 2013). Consequently, optimizing microbial fermentation represents an effective strategy for improving phosphorus availability in organic fertilizers.

Previous studies have investigated composting and biofertilizer production from various agro-industrial wastes, including food waste, livestock manure, agricultural residues, and sugar industry by-products (Lim et al., 2016). However, scientific information regarding the valorization of food processing cake waste using a double-molasses biofermentation system remains extremely limited. Furthermore, comprehensive evaluations integrating physicochemical characterization, nutrient transformation, heavy metal safety assessment, and agronomic performance have rarely been reported for this type of industrial residue.

Therefore, this study aims to evaluate the effectiveness of a double-molasses biofermentation system in converting food processing cake waste generated by PT Belfoods Indonesia into value-added organic fertilizer. Specifically, this research investigates changes in nutrient composition during fermentation, evaluates heavy metal safety, and assesses the agronomic performance of the final fertilizer through plant growth observations. The findings are expected to provide a practical waste valorization strategy that supports circular bioeconomy implementation while contributing to sustainable agricultural production and environmentally responsible food processing industries.

2. METHODS

2.1. Study Area and Raw Materials

This study was conducted using food processing cake waste generated from the production activities of PT Belfoods Indonesia, Nganjuk, East Java, Indonesia. The waste was collected immediately after the production process to minimize changes in its physicochemical characteristics prior to fermentation. The cake waste primarily consisted of biodegradable organic residues derived from food processing operations and served as the primary substrate for organic fertilizer production.

The biofermentation system employed a consortium of decomposer microorganisms activated by a double-molasses formulation consisting of fresh sugarcane juice (*Saccharum officinarum L.)* and palm sugar (*Arenga pinnata Merr.).* Fresh sugarcane juice provided readily available glucose, moisture, vitamins, and minerals, whereas palm sugar supplied concentrated sucrose as a sustained carbon source to support microbial metabolism throughout the fermentation process.

2.2 Experimental Design

The study adopted a longitudinal experimental design consisting of three consecutive fermentation stages to evaluate physicochemical transformations during organic fertilizer production.

a. Stage I (Raw Material Characterization).

Fresh food processing cake waste was collected and analyzed to determine its initial physicochemical characteristics before microbial inoculation.

b. Stage II (Double-Molasses Biofermentation).

The cake waste was thoroughly mixed with the double-molasses solution and inoculated with a consortium of decomposer microorganisms. Fermentation was carried out under controlled aerobic conditions until active microbial degradation stabilized. During this stage, microorganisms utilized simple sugars supplied by sugarcane juice and palm sugar as primary carbon sources, thereby accelerating the decomposition of complex organic compounds and nutrient mineralization.

c. Stage III (Mature Organic Fertilizer).

Following the stabilization phase, the fermented material was allowed to mature until a dark brown, crumbly, and odorless organic fertilizer was obtained. The mature product was subsequently subjected to laboratory analysis and agronomic evaluation.

2.3 Laboratory Analysis

Samples collected from each fermentation stage were analyzed independently by PT Saraswanti Indo Genetech (SIG), Bogor, an ISO/IEC 17025-accredited laboratory. Analytical procedures followed standardized national and international methods.

The measured parameters included:

a. Total nitrogen (N) determined using the modified Kjeldahl titration method.
b. Available phosphorus (P_2O_5), potassium (K), iron (Fe), and heavy metals (As, Cd, Hg, Pb, and Sn) quantified using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP–OES).

c. Organic carbon (C-organic) determined according to AOAC Method 967.05.
d. Ash content determined using AOAC Method 967.04.
e. Moisture content determined following SNI 7763:2024.
f. Soluble glucose determined using High-Performance Liquid Chromatography equipped with a Refractive Index Detector (HPLC-RID).

All laboratory analyses were conducted according to the analytical protocols established by PT Saraswanti Indo Genetech to ensure measurement accuracy and reliability.

2.4 Agronomic Performance Evaluation

The agronomic performance of the mature organic fertilizer was evaluated through a field bioassay using horticultural plants. Fertilizer was applied according to standard cultivation practices, and plant responses were monitored for 14 days.

Morphological observations included:

a. Leaf color intensity,
b. Leaf density,
c. Leaf expansion,
d. Stem thickness,
e. Overall plant vigor.

Plant performance before and after fertilizer application was documented using standardized digital photography under comparable environmental conditions to minimize observational bias.

2.5 Data Analysis

The experimental results were analyzed descriptively by comparing physicochemical characteristics across the three fermentation stages. Changes in nutrient composition during the biofermentation process were interpreted based on microbial mineralization mechanisms and supported by relevant scientific literature. Laboratory results were further evaluated against the Indonesian National Standard (SNI 7763:2024) for solid organic fertilizers to assess fertilizer quality and safety.

The agronomic observations were interpreted qualitatively by comparing morphological characteristics before and after fertilizer application to verify the effectiveness of the produced organic fertilizer in promoting vegetative plant growth.

3. FINDINGS AND DISCUSSION

3.1 Changes in Physicochemical Properties During Double-Molasses Biofermentation

The analysis parameters and units for Phase 1 (Raw Waste Cake – Nov 2025), Phase 2 (Intermediate – Double Molasses Fermentation Process), and Phase 3 (Final Organic Fertilizer Product – 2026) are presented in Table 1.

Analysis Parameters	**Unit**	**Fase 1: Raw Filter Cake Waste (Nov 2025)**	**Fase 2: Intermediate (Double Molasses Fermentation Process)**	**Fase 3: Organic Fertilizer End Product (2026)**
Glucose	%	*Not detected* (<0.2)	—	—
Moisture	%	—	85,99	—
C-Organic	%	—	43,63	—
Ash	%	—	3,47	—

Analysis Parameters	Unit	Fase 1: Raw Filter Cake Waste (Nov 2025)	Fase 2: Intermediate (Double Molasses Fermentation Process)	Fase 3: Organic Fertilizer End Product (2026)
Iron (Fe)	mg/100 g	—	65,28	—
Nitrogen (N)	%	0,17	—	0,69
Phosfor (P) / P_2O_5	mg/kg	60,47	—	5.264,77
Calium (K)	mg/100 g	16,85	—	—
Total N + P_2O_5 + K_2O	%	—	—	1,44

Table 1. Physicochemical characteristics of food processing cake waste during different stages of biofermentation.

The physicochemical characteristics of food processing cake waste changed considerably throughout the double-molasses biofermentation process (Table 1), indicating progressive microbial degradation and nutrient transformation. The initial substrate contained relatively low concentrations of total nitrogen (0.17%) and available phosphorus (60.47 mg kg^{-1}), suggesting that most nutrients were still incorporated within complex organic compounds. Such characteristics are commonly observed in freshly generated food processing residues, where nitrogen and phosphorus remain largely unavailable for direct plant uptake until microbial mineralization occurs (Bernal et al., 2009).

During the intermediate fermentation stage, the addition of the double-molasses formulation created favorable conditions for microbial metabolism. The recorded moisture content of 85.99% supported microbial proliferation, while the high organic carbon content (43.63%) reflected the abundance of biodegradable carbon substrates supplied by sugarcane juice and palm sugar. Easily metabolized sugars provide immediate energy for decomposer microorganisms, accelerating enzymatic degradation of proteins, carbohydrates, and other complex organic materials into simpler compounds (Chen et al., 2022). Consequently, microbial respiration and extracellular enzyme production increased, promoting rapid decomposition throughout the fermentation process.

The substantial increase in total nitrogen from 0.17% to 0.69% in the mature fertilizer demonstrates effective nutrient conservation and mineralization during biofermentation. Although part of the organic nitrogen was converted into inorganic forms available for plant uptake, microbial biomass also contributed to nitrogen retention within the compost matrix. Similar improvements in nitrogen availability have been reported in organic waste composting systems where adequate carbon sources stimulate microbial activity while minimizing nitrogen losses through volatilization (Lim et al., 2016).

The most remarkable finding was the dramatic increase in available phosphorus (P_2O_5), reaching 5,264.77 mg kg^{-1} in the final fertilizer. This result suggests that the double-molasses biofermentation system effectively enhanced phosphorus solubilization. Organic acids produced by fermentative microorganisms are known to dissolve insoluble phosphate complexes through acidification, chelation, and enzymatic hydrolysis, thereby increasing phosphorus availability for plants (Alori et al., 2017). The readily fermentable sugars contained in sugarcane juice and palm sugar likely intensified microbial metabolism, resulting in greater production of organic acids responsible for phosphorus mobilization.

Iron (Fe) concentration detected during the intermediate stage (65.28 mg 100 g^{-1}) further indicates active mineral transformation during fermentation. Iron is an essential micronutrient involved in chlorophyll biosynthesis, electron transport, and numerous enzymatic reactions in plants. The release of iron during decomposition reflects the progressive breakdown of organic complexes into bioavailable nutrients that may contribute to improved plant growth following fertilizer application (Agegnehu et al., 2017).

Overall, the observed physicochemical transformations demonstrate that the proposed double-molasses biofermentation system successfully accelerated organic matter decomposition and nutrient mineralization. Unlike conventional composting systems relying on a single carbohydrate source, the combined use of fresh sugarcane juice and palm sugar supplied complementary forms of readily available carbon that sustained microbial activity throughout the fermentation period. This strategy not only improved fertilizer nutrient quality but also enhanced the valorization potential of food processing cake waste as a sustainable agricultural input within a circular bioeconomy framework (Toop et al., 2017; European Commission, 2018).

3.2 Heavy Metal Safety Assessment

The safety of organic fertilizers derived from industrial organic residues is a critical prerequisite for their agricultural application. Although food processing waste is generally considered biodegradable and nutrient-rich, contamination by potentially toxic elements may occur depending on the raw materials and manufacturing processes. Therefore, comprehensive heavy metal analysis is essential to ensure environmental safety, prevent soil contamination, and protect the food chain (Bernal et al., 2009; Hargreaves et al., 2008).

The concentrations of arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), and tin (Sn) in the final organic fertilizer are presented in Table 2. All analyzed heavy metals were below the analytical detection limits of the ICP-OES instrument, indicating that no hazardous metal contamination was detected in the fertilizer produced through the double-molasses biofermentation system.

The absence of detectable heavy metals suggests that the food processing cake waste generated by PT Belfoods Indonesia possesses a relatively clean physicochemical profile and is suitable for biological conversion into organic fertilizer. Unlike municipal solid waste or sewage sludge, which often accumulate heavy metals from mixed waste streams, food processing residues generally originate from controlled manufacturing processes using food-grade raw materials. Consequently, the risk of introducing toxic metals into agricultural soils is substantially lower (Hargreaves et al., 2008; Kaza et al., 2018).

From an environmental perspective, heavy metals are of particular concern because they are persistent, non-biodegradable, and capable of accumulating in soils following repeated fertilizer applications. Once accumulated, toxic elements such as cadmium and lead may be absorbed by crop roots, subsequently entering the human food chain and posing long-term health risks. Therefore, continuous monitoring of heavy metal concentrations remains an essential quality control procedure during organic fertilizer production (Alloway, 2013).

The analytical results obtained in this study satisfy the safety requirements established by the Indonesian National Standard for solid organic fertilizers (SNI 7763:2024), which specifies maximum permissible concentrations of hazardous metals to ensure environmental protection and sustainable agricultural use. Compliance with these standards indicates that the produced fertilizer is suitable for agricultural application without increasing the risk of heavy metal accumulation in cultivated soils.

In addition to regulatory compliance, the absence of detectable arsenic, cadmium, mercury, lead, and tin demonstrates the effectiveness of the selected raw materials and controlled fermentation process. The double-molasses biofermentation system did not introduce external contamination during processing, indicating that the fermentation technology preserves the chemical safety of the final product while enhancing nutrient availability. This finding is particularly important because biofertilizer production technologies should improve nutrient quality without compromising environmental safety.

The heavy metal safety profile obtained in this study also supports the broader concept of sustainable waste valorization. Converting food processing cake waste into high-quality organic fertilizer not only reduces industrial waste disposal but also produces an environmentally safe agricultural input that aligns with circular bioeconomy principles. Safe nutrient recycling minimizes dependence on synthetic fertilizers while preventing secondary pollution associated with improper waste management (Toop et al., 2017).

Overall, the heavy metal assessment confirms that the proposed double-molasses biofermentation system successfully produces an organic fertilizer that satisfies both agronomic and environmental quality requirements. The absence of detectable toxic metals, combined with the significant improvement in nutrient composition, highlights the potential of food processing cake waste as a sustainable feedstock for producing environmentally friendly organic fertilizers suitable for long-term agricultural application.

3.3 Agronomic Performance of the Produced Organic Fertilizer

The agronomic effectiveness of the organic fertilizer produced through the double-molasses biofermentation system was evaluated by comparing plant morphological characteristics before and after fertilizer application over a 14-day observation period (Figure 2). Visual assessment demonstrated clear improvements in vegetative growth following fertilizer application, indicating that the fermentation process successfully enhanced nutrient availability and fertilizer functionality.

Prior to fertilizer application, the test plants exhibited typical symptoms of nutrient deficiency, including pale green leaves, relatively small leaf area, sparse foliage, and slender stems. These characteristics are commonly associated with insufficient nitrogen and phosphorus availability, which restrict chlorophyll biosynthesis, photosynthetic efficiency, root development, and overall plant growth (Marschner, 2012). Limited phosphorus availability also reduces ATP synthesis, thereby constraining cellular energy transfer required for active root elongation and biomass accumulation (Sharma et al., 2013).

Following the application of the mature organic fertilizer, substantial improvements in plant morphology were observed. Leaves became darker green, larger, and denser, while stems appeared thicker and more erect. These changes indicate enhanced vegetative development resulting from improved nutrient uptake and increased physiological activity. The darker green coloration suggests greater chlorophyll accumulation, whereas increased leaf expansion reflects enhanced photosynthetic capacity and biomass production (Agegnehu et al., 2017).

The significant increase in phosphorus (P_2O_5) concentration observed in the mature fertilizer (5,264.77 mg kg^{-1}) likely contributed to improved root growth and nutrient acquisition. Phosphorus is an essential macronutrient involved in energy metabolism, nucleic acid synthesis, membrane formation, and root architecture. Increased phosphorus availability stimulates root proliferation, enabling plants to absorb water and mineral nutrients more efficiently from the soil (Alori et al., 2017). This physiological response is consistent with the observed enhancement in canopy development after fertilizer application.

The increase in total nitrogen from 0.17% in the raw material to 0.69% in the mature fertilizer also contributed to the observed improvements in plant growth. Nitrogen is the primary constituent of chlorophyll molecules, amino acids, proteins, and numerous enzymes responsible for photosynthesis and biomass accumulation. Adequate nitrogen availability promotes rapid leaf formation, increases chlorophyll concentration, and enhances overall vegetative vigor (Marschner, 2012).

In addition to macronutrients, the presence of iron (Fe) detected during the biofermentation process may have supported chlorophyll biosynthesis and electron transport during photosynthesis. Iron functions as an essential micronutrient required for several oxidation-reduction enzymes and plays an important role in maintaining normal photosynthetic activity. Consequently, the combined availability of nitrogen, phosphorus, and iron likely produced synergistic effects on plant development (Agegnehu et al., 2017).

The improved plant performance observed in this study may also be attributed to the gradual nutrient release characteristics of organic fertilizers. Unlike synthetic fertilizers, which generally supply nutrients rapidly, organic fertilizers release nutrients progressively through continued microbial decomposition. This slow-release mechanism improves nutrient use efficiency while reducing nutrient losses through leaching and volatilization, ultimately supporting more sustainable crop production systems (Lim et al., 2016).

Furthermore, the biofermentation process likely generated beneficial microbial metabolites, including organic acids and plant growth-promoting substances, which may have further stimulated plant development. Previous studies have demonstrated that microbial fermentation products can improve nutrient solubilization, enhance rhizosphere microbial activity, and increase nutrient availability for plant uptake (Chen et al., 2022). Although microbial populations were not quantified in the present study, the observed morphological responses suggest that the fermentation process enhanced the biological quality of the produced fertilizer.

Overall, the field observations confirm that the organic fertilizer produced from food processing cake waste using the proposed double-molasses biofermentation system effectively promoted vegetative plant growth. The substantial improvements in leaf color, foliage density, stem strength, and overall plant vigor are consistent with the enhanced nutrient composition determined by laboratory analyses. These findings demonstrate that the proposed waste valorization strategy not only improves fertilizer quality but also provides practical agronomic benefits, supporting the application of food processing residues as sustainable organic fertilizer resources within a circular bioeconomy framework.

3.4 Implications for Circular Bioeconomy and Sustainable Waste Valorization

The increasing generation of organic waste from the food processing industry presents significant environmental and economic challenges. Conventional waste disposal practices, including landfilling and uncontrolled dumping, contribute to greenhouse gas emissions, unpleasant odors, and the loss of potentially valuable biomass resources. In contrast, waste valorization aims to transform organic residues into high-value products, thereby reducing environmental impacts while promoting resource efficiency within a circular bioeconomy (European Commission, 2018).

The present study demonstrates that food processing cake waste generated by PT Belfoods Indonesia can be successfully converted into a nutrient-enriched organic fertilizer through the proposed double-molasses biofermentation system. Rather than treating cake waste as a disposal burden, the fermentation process converts biodegradable organic residues into an agricultural input with measurable economic and environmental value. This transformation illustrates the practical implementation of circular bioeconomy principles, in which industrial by-products are continuously reintegrated into productive systems instead of being discarded (Dhillon & Kaur, 2016).

An important innovation of this study is the application of a double-molasses biofermentation system, combining fresh sugarcane juice and palm sugar as complementary carbon sources for microbial activation. Unlike conventional composting systems that commonly rely on a single carbon source, the dual-carbon approach provides both readily available glucose and sustained sucrose for microbial metabolism, thereby promoting efficient organic matter degradation and nutrient mineralization. The considerable increase in available phosphorus and total nitrogen observed during fermentation indicates that this approach can improve fertilizer quality while maintaining environmental safety.

From an industrial perspective, implementing this waste valorization strategy offers multiple economic advantages. The conversion of food processing residues into commercial organic fertilizer can substantially reduce waste handling and disposal costs while simultaneously generating an additional revenue stream through the production of value-added agricultural inputs. This approach supports the transition toward zero-waste manufacturing, where production residues are treated as secondary raw materials rather than environmental liabilities (Lin et al., 2022).

The environmental benefits are equally significant. Recycling organic waste into fertilizer reduces the volume of waste transported to landfills, lowers methane emissions generated during uncontrolled decomposition, and contributes to nutrient recycling within agricultural ecosystems. Furthermore, the absence of detectable heavy metals in the final product indicates that the proposed fertilizer can be safely applied without increasing the risk of soil contamination, thereby supporting long-term soil health and sustainable crop production.

The produced organic fertilizer also has the potential to reduce dependence on synthetic fertilizers. Excessive application of chemical fertilizers has been associated with soil degradation, nutrient imbalance, declining soil organic matter, and environmental pollution. Organic fertilizers improve soil physical structure, increase microbial diversity, enhance water-holding capacity, and gradually release nutrients, providing a more sustainable nutrient management strategy (Agegnehu et al., 2017). Consequently, integrating biofermented organic fertilizers into agricultural systems may improve both crop productivity and environmental resilience.

This study also contributes directly to several United Nations Sustainable Development Goals (SDGs). The proposed waste valorization strategy supports SDG 2 (Zero Hunger) by improving sustainable agricultural productivity through environmentally friendly fertilizer production. It contributes to SDG 12 (Responsible Consumption and Production) by promoting efficient utilization of industrial by-products and minimizing waste generation. In addition, the reduction of organic waste disposal and greenhouse gas emissions aligns with SDG 13 (Climate Action), while improved nutrient recycling and soil conservation contribute to SDG 15 (Life on Land).

Despite these promising findings, several limitations should be acknowledged. The present study evaluated fertilizer performance primarily through physicochemical characterization and short-term field observations. Future research should include replicated field experiments under different soil types and crop species, long-term evaluations of soil fertility, microbial community dynamics during fermentation, nutrient release kinetics, and comprehensive economic feasibility analyses. Such investigations would provide a more robust scientific basis for scaling up the proposed technology for commercial application.

Overall, the proposed double-molasses biofermentation system represents an effective and environmentally sound approach for valorizing food processing cake waste into high-quality organic fertilizer. The integration of nutrient recovery, waste minimization, and sustainable agricultural production demonstrates the potential of this technology to support industrial circularity while providing tangible environmental, agronomic, and economic benefits. Therefore, the technology offers a promising model for sustainable waste management within the food processing industry and may serve as a practical reference for broader implementation of circular bioeconomy practices.

4. CONCLUSION

This study demonstrated that food processing cake waste generated by PT Belfoods Indonesia can be effectively valorized into a high-quality organic fertilizer through a double-molasses biofermentation system utilizing fresh sugarcane juice and palm sugar as complementary carbon sources for microbial activation. The biofermentation process substantially improved nutrient availability, particularly total nitrogen and available phosphorus, while producing an environmentally safe fertilizer free from detectable concentrations of hazardous heavy metals. The enhanced nutrient composition was further supported by improved vegetative plant performance, indicating that the produced fertilizer possesses considerable agronomic potential.

Beyond improving fertilizer quality, this study highlights the feasibility of integrating industrial organic waste management with sustainable agricultural production through a circular bioeconomy approach. The proposed biofermentation system transforms food processing residues from an environmental liability into a value-added agricultural input, thereby reducing waste disposal while promoting nutrient recycling and resource efficiency.

The principal scientific contribution of this research lies in the introduction of the double-molasses biofermentation system as an effective strategy for accelerating organic matter decomposition and nutrient mineralization during the conversion of food processing cake waste into organic fertilizer.

This approach offers a practical and scalable alternative for agro-industrial waste valorization and supports the development of environmentally sustainable fertilizer production technologies.

Future studies should evaluate the long-term agronomic performance of the fertilizer under different soil conditions and crop species, investigate microbial community dynamics throughout the fermentation process, and assess the economic feasibility of large-scale industrial implementation. Such investigations will further strengthen the application of this technology in supporting sustainable agriculture and circular bioeconomy initiatives.

REFERENCES

Agegnehu, G., Nelson, P. N., & Bird, M. I. (2017). The effects of biochar, compost and their mixture on soil properties and crop performance: A review. Soil and Tillage Research, 170, 41–55. https://doi.org/10.1016/j.still.2017.03.007

Alloway, B. J. (2013). Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability (3rd ed.). Springer. https://doi.org/10.1007/978-94-007-4470-7

Alori, E. T., Glick, B. R., & Babalola, O. O. (2017). Microbial phosphorus solubilization and itspotential for sustainable agriculture. Frontiers in Microbiology, 8, 971. https://doi.org/10.3389/fmicb.2017.00971

AOAC INTERNATIONAL. (2023). Official Methods of Analysis of AOAC INTERNATIONAL (22nd ed.). Oxford University Press.

Bernal, M. P., Alburquerque, J. A., & Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. Bioresource Technology, 100(22), 5444–5453. https://doi.org/10.1016/j.biortech.2008.11.027

Badan Standardisasi Nasional. (2024). SNI 7763:2024 Pupuk Organik Padat. Jakarta: BSN.Dhillon, G. S., & Kaur, S. (Eds.). (2016). Agro-Industrial Wastes Valorization: Valorization for Green Energy and Bioproducts. CRC Press.

European Commission. (2018). A Sustainable Bioeconomy for Europe: Strengthening the Connection Between Economy, Society and the Environment. Publications Office of the European Union.

Food and Agriculture Organization of the United Nations. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. FAO.

Hargreaves, J. C., Adl, M. S., & Warman, P. R. (2008). A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems & Environment, 123(1–3), 1–14. https://doi.org/10.1016/j.agee.2007.07.004

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. World Bank.

Lim, S. L., Lee, L. H., & Wu, T. Y. (2016). Sustainability of using composting technology for organic solid waste treatment. Journal of Environmental Management, 169, 305–312. https://doi.org/10.1016/j.jenvman.2016.01.080

Marschner, P. (2012). Marschner's Mineral Nutrition of Higher Plants (3rd ed.). Academic Press.

PT Saraswanti Indo Genetech. (2025). Certificate of Analysis of Raw Food Processing Cake Waste. Bogor, Indonesia.

PT Saraswanti Indo Genetech. (2026a). Certificate of Analysis of Intermediate Biofermentation Product. Bogor, Indonesia.

PT Saraswanti Indo Genetech. (2026b). Certificate of Analysis of Mature Organic Fertilizer Produced from Food Processing Cake Waste. Bogor, Indonesia.

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. SpringerPlus, 2, 587. https://doi.org/10.1186/2193-1801-2-587

Toop, T. A., Ward, S., Oldfield, T., Hull, M., Kirby, M. E., & Theodorou, M. K. (2017). Towards sustainable feedstocks for the future bioeconomy. Biofuels, Bioproducts and Biorefining, 11(4), 640–652. https://doi.org/10.1002/bbb.1761