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Organic Waste Management Innovation through Composting Technology with Local Bio-Activators

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ABSTRACT. This research is part of a strategic research program in environmental technology and renewable energy focused on climate change mitigation. Organic waste management through composting technology is a strategic approach to reduce waste generation and the potential for methane (CH_4) emissions from anaerobic decomposition. This study aimed to analyze the effectiveness of local microorganism (MOL) bioactivators, namely rice MOL (P1), banana mob MOL (P2), and fruit MOL (P3), in accelerating composting, compared to controls (without the addition of MOL). The results showed that fruit MOL (P3) is the most effective bioactivator for accelerating decomposition and improving compost quality. This treatment achieves the fastest maturity in 40 days with the lowest C/N ratio and the highest macronutrient content (Nitrogen (N), Phosphorus (P), Potassium (K)) compared to other treatments. These findings confirm that the application of local bioactivators can significantly improve the efficiency of campus organic waste management and support environmental sustainability.

INTRODUCTION

Organic waste management has been a key focus in studies on climate change mitigation, particularly because it contributes to methane (CH_4) emissions from anaerobic decomposition in landfills. Organic waste from landscaping activities and canteen operations is among the largest types of waste in the campus environment. Without proper handling, this waste can accumulate greenhouse gas emissions and increase the burden on waste management systems (Ahmad *et al*., 2023; Deswati *et al*., 2023; Nagel *et al*., 2024). This condition requires research to develop organic waste treatment methods that are not only effective but also sustainable and environmentally friendly.

Composting is a technology widely studied as a scientific solution because it can convert organic matter into nutritious products through aerobic processes. Previous research, such as the recent study by Pérez *et al*. (2023), empirically shows that composting can reduce potential greenhouse gas emissions by up to 38-84% compared to conventional stockpiling methods. However, the composting process itself remains at risk of producing methane and nitrogen oxide emissions if the process parameters are not optimally controlled (Nordahl *et al*., 2023; Ross *et al*., 2023; Wanapat *et al*., 2024). However, most previous research has focused solely on technical efficiency, and there is little that integrates the analysis of methane gas emissions' mitigation potential as the main variable. This *gap* underscores the urgency of this research, in line with the recommendations of Sharma *et al*. (2024) to evaluate specific composting strategies in urban and institutional environments to ensure sustainability.

To address these challenges, this study applies controlled composting technology innovations that use bioactivators derived from local microorganisms (MOL). The use of MOL is emphasized as a novel approach because it offers an alternative that is more economical and better adapted to the characteristics of local waste

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than commercial activators. This approach combines the identification of campus waste characteristics with experimental testing to obtain empirical data on decomposition rates and the quality of the compost produced.

Based on the research gap, this study aims to provide a comprehensive understanding of campus organic waste generation, its characteristics, and its potential for methane emissions. This research involves the quantitative and qualitative identification of organic waste generated from gardening and canteen activities, to obtain empirical data as a basis for designing an appropriate treatment system. This approach is important, as variations in organic waste composition directly affect the effectiveness of the composting process and the quality of the compost produced.

This study also tested the application of controlled composting technology using MOL-based bioactivators. The use of MOL is an innovative aspect because it offers a bioactivator alternative that is more economical, easier to obtain, and potentially better adapted to local organic waste characteristics. The composting process is monitored by measuring key parameters such as temperature, pH, humidity, and C/N ratio, which scientifically determine the success of biodegradation. A composting performance analysis was conducted to evaluate decomposition rate, final compost quality, and the estimated reduction in methane emission potential compared to the landfill disposal scenario.

Overall, this study resulted in a holistic approach that combines waste generation analysis, optimization of composting technology, and evaluation of its impact on greenhouse gas mitigation. The results of the research are expected to make a scientific contribution by providing an effective and sustainable compost-based organic waste management model, especially in the campus environment. In addition to expanding the scientific literature on organic composting and decomposition, this research also has the potential to serve as a basis for further research on technology improvement, the development of local bioactivators, and life-cycle *assessment* of organic waste management.

RESEARCH METHODS

This study uses an experimental design to evaluate the effectiveness of composting technology for processing campus organic waste. This design allows controlled observation of the decomposition process, comparison of bioactivator effectiveness, and evaluation of the compost's physical and chemical parameters. In parallel, this study is descriptive, mapping the characteristics of organic waste generated from campus landscaping and canteen activities, thereby providing an overview of the initial conditions that serve as the basis for developing waste management technology (Lakhouit, 2025).

The approach used was a mixed approach, combining quantitative and qualitative methods. A quantitative approach was applied to measure the parameters of the composting process, such as temperature, pH, humidity, C/N ratio, and final quality of compost according to certain standards, to ensure the validity of the results and compare the performance of the compost (An *et al*., 2025). A qualitative approach was used to analyze conditions for organic waste management, understand operational constraints, and evaluate the potential application of sustainable management models (Bruno *et al*., 2025). The integration of these two approaches enables the research to assess the technical effectiveness and practical relevance of composting technology.

Preparation Stage

The initial stage of research includes the manufacture of three types of Local Microorganism (MOL) bio-activators: P1 is MOL stale rice, P2 is MOL banana mound, and P3 is MOL fruit waste. MOL was made by chopping raw materials, mixing them with molasses/sugar and water (ratio 1:1:5), and fermenting anaerobically for 7 – 14 days (EL-Moslamy *et al*., 2023; Zhu *et al*., 2023; Li *et al*., 2024). In parallel, the initial collection and characterization of organic waste samples (dried leaves, grass clippings, vegetable residues, and fruit peels) were carried out to obtain baseline data, including moisture content and initial C/N ratios. All organic waste was chopped to a size of ±2 – 5 cm to ensure homogenization and support microbial activity during composting.

Experiment Stage / Composting Process

A total of 20 kg of organic waste was put into each of the 12 ventilated composter units. Composting was carried out in four treatments: P0 is control without bio-activator (water to 50 – 60% humidity), P1is MOL stale rice, P2 is MOL banana mound, and P3: MOL fruit waste. Bio-activators were applied evenly by watering or spraying. Process parameters, including temperature, pH, and humidity, are monitored regularly. Compost reversal was carried out every 5 – 7 days to maintain optimal aeration. The composting process continued until the compost was fermented, as indicated by temperature stability, color changes, and soil aroma.

Laboratory Analysis and Evaluation Stage

After the compost was cooked, the sample was analyzed in the laboratory. The parameters tested include the C/N ratio using Walkley-Black method for C-organic and Kjeldahl method for N-total, P and K rates were determined using UV-Vis spectrophotometer and AAS, and moisture content and final pH. The results of the analysis were used to compare the effectiveness of various MOLs in accelerating decomposition and improving compost quality, as well as to evaluate the potential application of composting technology at the micro scale.

RESULTS AND DISCUSSION

The study's results show that the use of MOL bioactivators significantly influences the dynamics of the composting process. These biological interventions have been shown to accelerate the rate of exothermic reactions, stabilize chemical parameters early, and improve the retention of macronutrients in the final product.

Temperature Dynamics and Microbiological Activity

The temperature profile in Figure 1 shows that treatment with MOL, specifically P3 (Fruit MOL), triggers a more aggressive temperature increase than control. P3 reached the highest thermophilic peak of 60.5 °C on day 7, while control (P0) only reached 49 °C with a slower rate of rise. A drastic increase in temperature at P3 indicates an instantaneous energy supply from simple glucose in fruit waste, which spurs the rapid metabolism of thermophilic bacteria.

These findings are in line with a recent study by Martínez-Gallardo *et al*. (2023), which reported that fruit waste-based bio-activators accelerated the attainment of the thermophilic phase (temperature >50 °C) within 5 days. This thermophilic phase is crucial because it serves as a natural sanitation mechanism to kill pathogens and weed seeds (Thalavaiasundaram *et al*., 2023). In contrast, in control treatments, low temperatures prolong composting and increase the risk of partial anaerobic conditions. A gradual decrease in temperature after day 21 across all MOL treatments indicates the depletion of biodegradable organic matter and the earlier onset of the ripening (curing) phase.

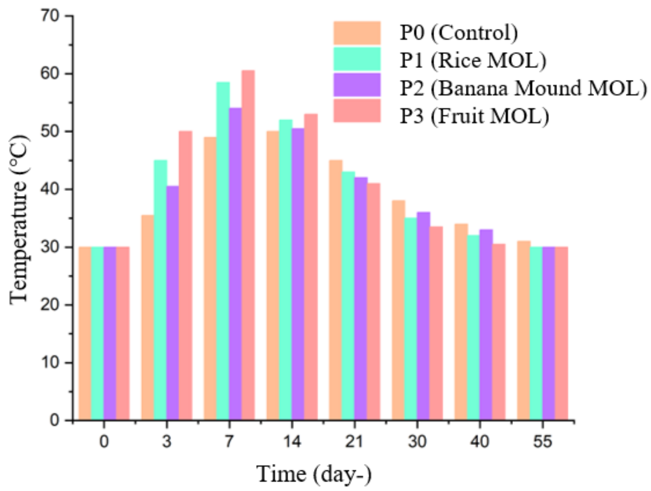

Figure 1. Profile of temperature changes during composting with different types of bio-activators.

Changes in pH and Process Stability

In line with temperature fluctuations, the pH profile (Figure 2) shows a typical decomposition pattern. The P3 treatment shows the best buffering ability, allowing the extreme acid conditions at the beginning of the process to be neutralized faster than in P0. Neutral pH stability (6.8 – 7.0) was achieved on day 40 with the P3 treatment. This phenomenon is closely related to the dominance of the *Lactobacillus spp.* population and Yeast in fruit MOL that works synergistically degrades volatile organic acids into stable end products (Thaw *et al*., 2020; Anderson and Mott, 2023; Luca *et al*., 2024; Feng *et al*., 2025). The earlier achievement of neutral pH in P3 is a biological indicator that the mineralization process has been completed and the compost has reached maturity.

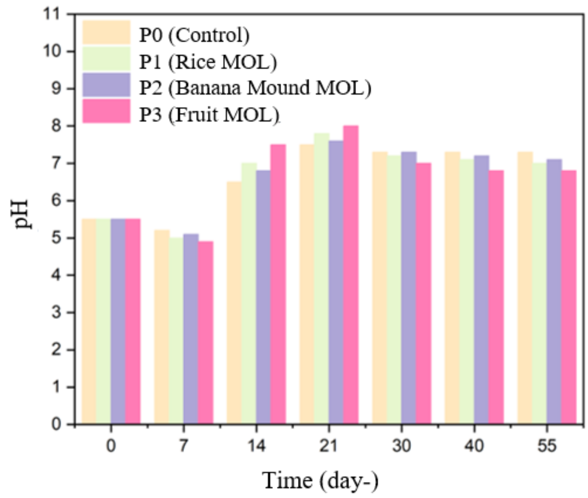

Figure 2. Dynamics of pH changes in various treatments during composting time.

Effectiveness of Bio-Activators in Reducing C/N Ratio

Figure 3 visualizes the acceleration of decomposition characterized by a decrease in the C/N ratio. P3 treatment showed the sharpest decrease, reaching a ratio of 12.5 on the 40th day, which falls within the very mature category (ratio <15) according to the SNI 19-7030-2004 standard. The significant decrease in the C/N ratio in the P3 treatment in this study reinforces the findings of Fadhil *et al.* (2025), who reported that the use of bio-activators based on local microorganisms can reduce the C/N ratio by up to 60% more efficiently than natural composting. This is significantly different from the control (P0), which, on the graph, still shows a C/N ratio above 19 in the same period. Fruit waste-based bio-activators accelerate organic carbon degradation by 40-50% compared with natural processes. The 40-day ripening time achieved by fruit MOL is relatively fast because bio-activators from fruit waste and rumen are effective in accelerating the degradation of organic matter, enabling it to reach the SNI ripeness standard within 30 – 45 days (Fadhil *et al.*, 2025).

The low C/N ratio at P3 indicates high nitrogen availability for plants, as decomposing microbes have completed their nitrogen-immobilization cycle. These findings are in line with Phutela *et al.* (2025), who reported similar patterns in the application of fruit waste bio-enzymes. The study showed that fruit-based activators initiated the thermophilic phase earlier (day 3) and accelerated temperature stabilization, an indicator of the end of decomposition. This validates that the microbial consortium in fruit MOL not only excels in nutrient retention (NPK) but also in carbon degradation efficiency.

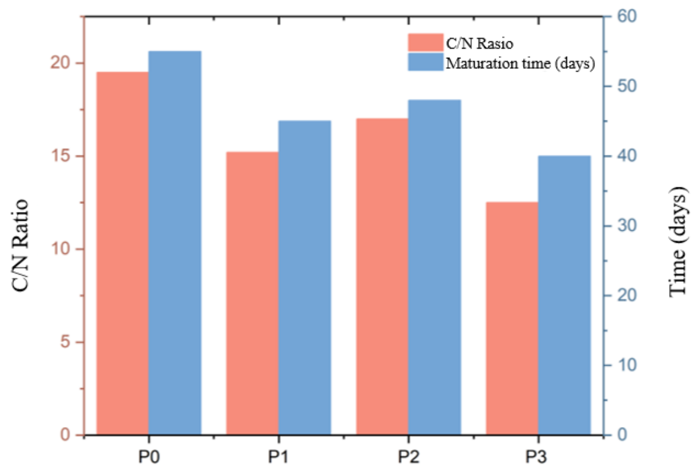

Figure 3. Degradation profiles of C/N ratios and time of compost maturity at various treatments.

N, P, K Content and Compost Quality

The final quality of compost is largely determined by its macronutrient content. Based on the visualization in Figure 4, the P3 treatment shows the highest bar across all parameters. Quantitative analysis showed that P3 compost contained 1.60% Nitrogen (N), 0.62% Phosphorus (P), and 1.85% Potassium (K). This value far exceeds the minimum threshold of composting standards (Min N 0.40%; P 0.10%; K 0.20%). The significant increase in N levels in P3 is thought to be due to the dual activity of nitrogen-fixing bacteria (*Azotobacter sp.*) naturally present in fruit fermentation, as well as minimal nitrogen loss as ammonia gas due to the rapid pH stabilization process. Meanwhile, the high K level (1.85%) in P3 is directly correlated with the fruit peel raw material, which is naturally rich in potassium, making this compost highly potential as a high-quality organic fertilizer.

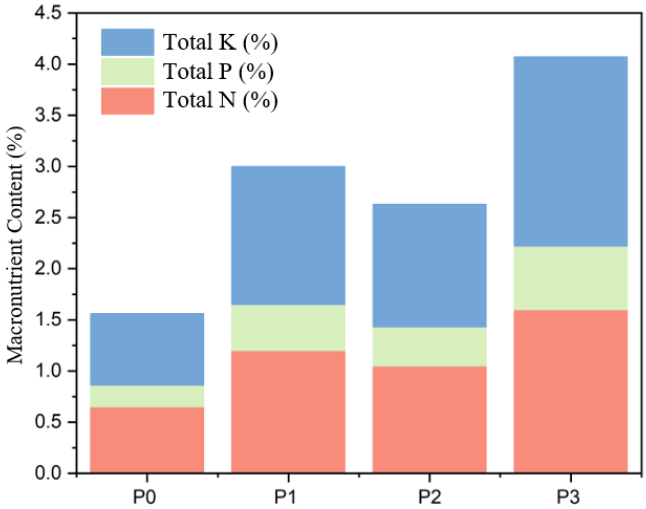

Figure 4. Comparison of macronutrient content (N, P, K) in the final compost.

The findings of this study on high nutrient status are consistent with the latest research. The ability of fruit MOL to produce high levels of N and P demonstrates that local bio-activators are as effective as commercial inoculants at retaining nutrients during the mineralization process (Musa and Elnour, 2024). In addition, the accumulation of potassium, which is dominant in the final product, confirms that the utilization of fruit waste is very effective as a provider of macronutrient K, which is crucial for plant growth (Carmona and Guagliardi, 2022; Khammarnia *et al*., 2024).

CONCLUSION

Based on the study's results, it can be concluded that the application of Local Microorganism (MOL) bioactivators significantly improves the efficiency of organic waste composting. Specifically, fruit MOL (P3) proved to be the most superior variant, accelerating compost ripening to 40 days, shorter than the control (55 days). This treatment also yields the best final product quality, with the lowest C/N ratio (12.5) and the highest macronutrient retention (N, P, and K). The implementation of this method is highly relevant as an independent waste management strategy in the campus environment to support the mitigation of carbon emissions. Further research is recommended to quantify greenhouse gas (GHG) emissions directly during the process to validate the environmental impact of these innovations.

CONFLICT OF INTEREST

There are no conflicts of interest in this article.

AUTHOR CONTRIBUTION

EPR: Research Conceptualization and Design, Composting Experiments, Data Collection, Laboratory Analysis, and Initial Manuscript Writing; HP: Methodology Guidance, Experimental Supervision, Data Validation, and Manuscript Revision for Scientific Quality; NR: Data Analysis, Interpretation of Results, and Preparation of Discussions and Conclusions.

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REFERENCES

Ahmad, I., Ibrahim, N.N.B., Abdullah, N., Koji, I., Mohamad, S.E., Khoo, K.S., Cheah, W.Y., Ling, T.C., and Show, P.L., 2023. Bioremediation Strategies of Palm Oil Mill Effluent and Landfill Leachate Using Microalgae Cultivation: An Approach Contributing towards Environmental Sustainability. *Chinese Chemical Letters*, 34, 107854. https://doi.org/10.1016/j.cclet.2022.107854.

An, G., Li, W., Gao, X., Luo, Y., Xu, Z., Li, G., Luo, W., and Nghiem, L.D., 2025. Membrane Coverage to Retain Gas Emission during Organic Waste Composting: Performance and Moisture Impacts. *Journal of Membrane Science*, 722, 123841. https://doi.org/10.1016/j.memsci.2025.123841.

Anderson, K.E., and Mott, B.M., 2023. Ecology of Pollen Storage in Honey Bees: Sugar Tolerant Yeast and the Aerobic Social Microbiota. *Insects*, 14, 265. https://doi.org/10.3390/insects14030265.

Bruno, D., Orlando, M., Testa, E., Carnevale Miino, M., Pesaro, G., Miceli, M., Pollegioni, L., Barbera, V., Fasoli, E., Draghi, L., Baltrocchi, A.P.D., Ferronato, N., Seri, R., Maggi, E., Caccia, S., Casartelli, M., Molla, G., Galimberti, M.S., Torretta, V., Vezzulli, A., and Tettamanti, G., 2025. Valorization of Organic Waste through Black Soldier Fly: On the Way of a Real Circular Bioeconomy Process. *Waste Management*, 191, 123–134. https://doi.org/10.1016/j.wasman.2024.10.030.

Carmona, F.J., Guagliardi, A., and Masciocchi, N., 2022. Nanosized Calcium Phosphates as Novel Macronutrient Nano-Fertilizers. *Nanomaterials*, 12, 2709. https://doi.org/10.3390/nano12152709.

Deswati, D., Tetra, O.N., Hayati, M., Putra, A., Fitri, W.E., Suparno, S., and Pardi, H., 2023. Preliminary Detection of Microplastics in Surface Water of Maninjau Lake in Agam, Indonesia. *AACL Bioflux*, 16.

EL-Moslamy, S.H., Elnouby, M.S., Rezk, A.H., and El-Fakharany, E.M., 2023. Scaling-up Strategies for Controllable Biosynthetic ZnO NPs Using Cell Free-Extract of Endophytic Streptomyces Albus: Characterization, Statistical Optimization, and Biomedical Activities Evaluation. *Scientific Reports*, 13, 3200. https://doi.org/10.1038/s41598-023-29757-9.

Fadhil, M., Yanti, S., Irfan, Sulaiman, I., and Noviasari, S., 2025. Study of MOL Production from Various Fruit Waste Mixtures and Fermentation Length. *IOP Conference Series: Earth* and *Environmental Science*, 1476, 012089. https://doi.org/10.1088/1755-1315/1476/1/012089.

Feng, W., Wang, C., Liu, M., Wang, H., and Wu, Z., 2025. A Core-Shell Structured Crystalline@amorphous MnO2 with Enhanced Plasma Catalytic Degradation Performance for Volatile Organic Sulfur Compounds and Degradation Mechanism Exploration. *Journal of Hazardous Materials*, 482, 136597. https://doi.org/10.1016/j.jhazmat.2024.136597.

Khammarnia, M., Ansari-Moghaddam, A., Kakhki, F.G., Clark, C.C.T., and Barahouei, F.B., 2024. Maternal Macronutrient and Energy Intake during Pregnancy: A Systematic Review and Meta-Analysis. *BMC Public Health*, 24, 478. https://doi.org/10.1186/s12889-024-17862-x.

Lakhouit, A., 2025. Revolutionizing Urban Solid Waste Management with AI and IoT: A Review of Smart Solutions for Waste Collection, Sorting, and Recycling. *Results in Engineering*, 25, 104018. https://doi.org/10.1016/j.rineng.2025.104018.

Li, J.-L., Li, W.-L., Zhang, J., Pang, Y., Xiong, J., Wu, P., Wei, B., Li, X.-J., Huang, Q., Tang, Q.-H., Zhao, C.-H., Wang, Q., Liu, Z.-L., Chen, Y., Dong, Z., Zhao, Y., and Guo, J., 2024. Seasonal Dynamics of the Microbiota and Nutritional Composition in Bee Bread from Apis Cerana and Apis Mellifera Colonies. *Food Research International*, 190, 113905. https://doi.org/10.1016/j.foodres.2023.113905.

Luca, L., Pauliuc, D., and Oroian, M., 2024. Honey Microbiota, Methods for Determining the Microbiological Composition and the Antimicrobial Effect of Honey – A Review. *Food Chemistry: X*, 23, 101524. https://doi.org/10.1016/j.fochx.2024.101524.

Martínez-Gallardo, M.R., Estrella-González, M.J., Suárez-Estrella, F., López-González, J.A., Jurado, M.M., Toribio, A.J., and López, M.J., 2023. Effect of Upstream Bioactivation of Plant Residues to Accelerate the Composting Process and Improve Product Quality. *Agronomy*, 13. https://doi.org/10.3390/agronomy13061638.

Musa, K.H., and Elnour, A.A.M., 2024. Advances and Future Perspectives in Biotechnological and Bioconversional of Dates Byproducts. *Journal of Agriculture* and *Food Research*, 16, 101145. https://doi.org/10.1016/j.jafr.2024.101145.

Nagel, B., Anggraini, E., Buhari, N., Gray, S., Partelow, S., and Schlüter, A., 2024. Mental Models of Aquaculture Governance in Indonesia. *Sustainability Science*, 19, 1825–1845. https://doi.org/10.1007/s11625-024-01545-y.

Nordahl, S.L., Preble, C. V., Kirchstetter, T.W., and Scown, C.D., 2023. Greenhouse Gas and Air Pollutant Emissions from Composting. *Environmental Science & Technology*, 57, 2235–2247. https://doi.org/10.1021/acs.est.2c05846.

Pérez, T., Vergara, S.E., and Silver, W.L., 2023. Assessing the Climate Change Mitigation Potential from Food Waste Composting. *Scientific Reports*, 13, 7608. https://doi.org/10.1038/s41598-023-34174-z.

Phutela, U.G., Arora, R., Kumar, A., and Aggarwal, Y., 2025. Potential Use of Mosambi Peel-Based Bioenzymes for the Wound Management in Animals. *The Indian Journal of Animal Reproduction*, 46, 61–67. https://doi.org/10.48165/ijar.2025.46.01.10.

Ross, F.W.R., Boyd, P.W., Filbee-Dexter, K., Watanabe, K., Ortega, A., Krause-Jensen, D., Lovelock, C., Sondak, C.F.A., Bach, L.T., Duarte, C.M., Serrano, O., Beardall, J., Tarbuck, P., and Macreadie, P.I., 2023. Potential Role of Seaweeds in Climate Change Mitigation. *Science of The Total Environment*, 885, 163699. https://doi.org/10.1016/j.scitotenv.2023.163699.

Sharma, P., Nagabhooshanam, N., Kumar, R., Sharma, K., and Vani, S., 2024. Exploration of Composting Strategies for Sustainable Organic Waste Management in Urban Environments. *Global Nest Journal*, 26. https://doi.org/10.30955/gnj.05970.

Thalavaiasundaram, S., Ajwa, H., and Stevens, M.C., 2023. Dose-Response of Pests to Ethanedinitrile Dose-Response of Weed Seeds, Soil Borne Pathogens, and Plant-Parasitic Nematodes to Ethanedinitrile. *Australasian Plant Pathology*, 52. https://doi.org/10.1007/s13313-023-00905-z.

Thaw, M.M., Aung, S.T., and Khine, M.Y., 2020. Biomedical Applications of Zinc Oxide Nanoparticles from Spirulina Platensis in Yae Khar Lake, Myanmar. 9th Virtual Nanotechnology Conference, Nano Poster 2020-017.

Wanapat, M., Prachumchai, R., Dagaew, G., Matra, M., Phupaboon, S., Sommai, S., and Suriyapha, C., 2024. Potential Use of Seaweed as a Dietary Supplement to Mitigate Enteric Methane Emission in Ruminants. *Science of The Total Environment*, 931, 173015. https://doi.org/10.1016/j.scitotenv.2024.173015.

Zhu, J., Wang, S., Wang, C., Wang, Z., Luo, G., Li, J., Zhan, Y., Cai, D., and Chen, S., 2023. Microbial Synthesis of Bacitracin: Recent Progress, Challenges, and Prospects. *Synthetic* and *Systems Biotechnology*, 8, 314–322. https://doi.org/10.1016/j.synbio.2023.03.009.