Menara Perkebunan 2025, 93(2), 116-123
p-ISSN: 0125-9318/ e-ISSN: 1858-3768
http://dx.doi.org/10.22302/iribb.jur.mp.v93i2.677
Accreditation Number: 177/E/KPT/2024

Techno-economic analysis and scale-up process simulation of compost production from OPEFB using rapid decomposition system (RDS) technology with SuperPro Designer®

Silva LATISYA[1], Firda DIMAWARNITA[1*], Yora FARAMITHA[1], Mujahidah KAMILAH[2], Serarifi Elagin HARAHAP[1] & Didiek Hadjar GOENADI[1]

[1)] Indonesian Oil Palm Research Institute, Jl.Taman Kencana No. 1, Bogor, 16128, Indonesia
[2)] Bioengineering, School of Life Sciences and Technology, Institut Teknologi Bandung Jl.Let. Jen. Purn. Dr. (HC) Mashudi No. 1 Jatinangor, Sumedang, 45363, Indonesia

Received 8 Sep 2025/ Revised 3 Oct 2025/ Accepted 31 Oct 2025

Abstract

Oil palm empty fruit bunches (OPEFB) are biomass waste from oil palm mills (POM) that are abundant and potential as feedstock for compost. However, the conventional composting process for OPEFB is time-consuming and inefficient. A Rapid Decomposition System (RDS) technology has been developed to accelerate the decomposition of OPEFB into compost, utilising microorganisms that produce ligninolytic and cellulase enzymes. RDS combines chemical delignification (using H_2O_2) and biological processes simultaneously, which significantly reduces the composting period (generally 2–3 months to only about 45 h per batch), while also producing valuable by-products such as fulvic acid and growth stimulating hormone (GSH). The system can reduce OPEFB volume, thereby improving efficiency and sustainability. This study aims to simulate the scale-up of the RDS compost production process from OPEFB and financial feasibility. A simulation production of 5 kg of RDS compost at a larger scale (scale-up) using SuperPro Designer® software has been conducted. The results showed that 100 kg of OPEFB could produce 32.67 kg of RDS compost with a process time of 45.01 hours per batch. The financial scenario, which covers the main product (compost) and by-products (GSH and fulvic acid), yields a gross margin of 55%, a return on investment (ROI) of 68.67%, and a payback period of 1.46 years. The techno-economic feasibility analysis yielded an internal rate of return (IRR) of 41.08% and a nett present value (NPV) of $24,743,000, indicating that this technology is feasible and profitable for scaling up to industrial scale.

[Keywords: Feasibility, organic fertilizer, palm oil biomass, rapid composting, software simulation]

Introduction

Empty palm fruit bunches (OPEFB) are biomass waste from the processing of oil palm fresh fruit bunches (FFB), with an abundance of up to around 23% of the weight of FFB (Nabila et al., 2023). In 2023, Indonesia's palm oil production was recorded at 46.9 million tons, generating approximately 10 million tons of OPEFB waste, with projections indicating a continued annual increase (Sentana et al., 2010; BPS-Statistics Indonesia, 2024). The high volume of waste has created challenges in management, particularly due to the slow natural decomposition of OPEFB and its relatively low economic value due to poor waste management, as it has been primarily utilised as mulch and boiler fuel (Harahap et al., 2021; Zaman et al., 2024). Despite this, OPEFB still contains a significant amount of nutrients, including carbon (42.8%), potassium oxide (2.9%), nitrogen (0.8%), phosphorus pentoxide (0.22%), magnesium oxide (0.30%), and micronutrients such as copper and zinc (Haryanti et al., 2014), indicating its high potential as a feedstock for organic compost-based fertilisers, which can improve soil structure and pH, increase cation exchange capacity, and reduce dependence on chemical fertilisers (Mansyur et al., 2021; Pramana et al., 2021; Iswahyudi & Iskandar, 2023).

*)Corresponding author: firda.dimawarnita@gmail.com

Menara Perkebunan is DOAJ indexed Journal and accredited as Sinta 2 Journal (https://sinta.kemdikbud.go.id/journals/profile/3125)
How to Cite: Latisya, S., Dimawarnita, F., Faramitha, Y., Kamilah, M., Harahap, S.E. & Goenadi, D.H. (2025). Scale-up process simulation and techno-economic analysis of compost production from OPEFB using rapid decomposition system (RDS) technology with SuperPro Designer®. *Menara Perkebunan, 93*(2), 116-123. http://dx.doi.org/10.22302/iribb.jur.mp.v93i2.677

Compost is a product of the organic material decomposition process carried out by living organisms. In general, this process takes up to several months to reach a state of maturity (Listyarini et al., 2024; Sakiah et al., 2024). The extensive duration of decomposition has become the primary challenge in industrial scale composting development, due to the significant land requirements and high operational costs (Nurrohmanysah et al., 2019). The presence of high lignin content in OPEFB is the primary cause of the slow composting process, as lignin forms complex bonds with cellulose and hemicellulose, thereby inhibiting the activity of cellulolytic enzymes (Howard et al., 2013; Aulia et al., 2024).

The Rapid Decomposition System (RDS) technology was developed as an innovative solution to accelerate the OPEFB composting process through a chemical delignification approach combined with biodelignification and simultaneous microorganism-based composting. This technology leverages the biological capabilities of *Trichoderma* sp. and *Fomitopsis meliae*. *Trichoderma* sp. is known to produce cellulase enzymes that hydrolyse cellulose into glucose (Dimawarnita et al., 2024; Sakiah et al., 2024). On the other hand, *Fomitopsis meliae* is a type of wood-rotting fungus that can produce ligninolytic enzymes to degrade lignin, as well as produce cellulase enzymes (Civzele & Mezule, 2024; Karunarathna et al., 2025).

The effectiveness of RDS technology in accelerating OPEFB composting at the laboratory scale has prompted the importance of further development to an industrial scale. This could be performed using a scale-up simulation approach as an efficient method for designing and evaluating processes both technically and economically before actual operation. Simulation enables a comprehensive understanding of the physical parameters and chemical reactions involved in process optimisation (Bentolila et al., 2018). Therefore, this study aims to evaluate the economic feasibility of RDS technology in industrial-scale OPEFB processing through a simulation approach.

The industrial-scale RDS composting process was simulated using SuperPro Designer®. SuperPro Designer® is a process simulator that supports both batch and continuous operations. It integrates manufacturing processes with environmental treatments, allowing comprehensive evaluation and optimization. In addition to conventional chemical processes, the software is widely applied to model bioconversion systems involving microbial activity, such as fermentation, enzymatic hydrolysis, and solid-state bioprocessing (Intelligen Inc, 2025). These features are particularly relevant for simulating composting process that utilize microbial consortia, since the program can incorporate biological reaction kinetics, nutrient consumption, and biomass growth within its mass and energy balance framework.

Materials and Methods

The simulation of RDS for compost production from OPEFB was developed using SuperPro Designer® version 14 (Intelligen Inc., USA). This work aimed to scale up and evaluate the technical and economic feasibility of the RDS process, which was originally operated at a mini-pilot scale with a 5 kg OPEFB feed. The simulation model was constructed based on the actual process parameters obtained experimentally and was adapted to the standard unit operations available in the SuperPro Designer® database.

RDS technology for compost production from OPEFB

RDS represents an integrated innovation designed to overcome the limitations of conventional OPEFB composting, which typically requires several months and large operational areas due to the slow natural decomposition of lignocellulosic biomass. Traditional organic fertilizer production methods emphasize biological aspects, relying solely on microbial degradation, while often neglecting the essential physico-chemical factors that influence decomposition efficiency. To address these challenges, the RDS technology was engineered to combine chemical, biological, and physical mechanisms in a synergistic process.

The technology involves a three-stage decomposition process—namely peroxidation, bio-decomposition, and maturation. First, the shredded OPEFB fibers (3–5 cm) undergo peroxidation using a 12.5% hydrogen peroxide (H_2O_2) solution. The mixture is processed in a bioreactor, facilitating oxidative delignification and partial cellulose hydrolysis. The second stage, bio-decomposition, is initiated by adding a decomposer mixture along with *Trichoderma* sp. and *F. meliae* inoculum. The mixture is homogenized and incubated at 40°C, promoting rapid enzymatic degradation of polysaccharides. Finally, during the maturation stage, the material remains in the reactor for 24 h, allowing stabilization and humification to occur. The by-product recovery section was designed to simulate the extraction of fulvic acid and growth stimulating hormone (GSH). Fulvic acid is extracted using a microwave-assisted extractor (MAE) (Dimawarnita et al., 2024). The recovery of GSH was represented as a secondary oxidative process using a 21% H_2O_2 solution.

Within this integrated system, the OPEFB substrate achieves full compost maturity within 24 hours, resulting in an organo-humic nutrient product with a C/N ratio between 25–30, suitable for agronomic application. Laboratory analysis of

RDS compost revealed progressive stabilization, with C/N ratios of 25 on day 1, 20 on day 7, and 18 on day 14, confirming the rapid and sustainable decomposition performance of the system.

Process modelling and simulation configuration

The SuperPro Designer® model was constructed to represent the scale-up of the RDS process using equivalent process units available in the simulator. The modelled system consisted of four main process sections:
(1) feedstock preparation and delignification,
(2) bio-decomposition and composting,
(3) drying and stabilization, and
(4) by-product recovery.

Equivalent SuperPro Designer® unit operations were used to simulate each stage: shredding, leaching, bioreactor, tray drying, microwave extraction, and liquid–solid separation. Although the real RDS reactor integrates both chemical and biological reactions within a single chamber, in the simulation it was represented as a sequence of leaching and bioreactor units to capture the kinetics of peroxidation and microbial conversion. The process was modelled in batch mode to reflect the cyclic operational nature of the RDS system.

Simulation scenarios

Three simulation scenarios were developed to evaluate the technical and financial implications of product diversification:

1. Scenario 1 – Compost-only production: Simulation of compost as the single output to establish a baseline economic reference.
2. Scenario 2 – Compost + GSH production**:** Addition of GSH recovery as a by-product stream.
3. Scenario 3 – Compost + GSH + Fulvic acid production**:** Full valorization model, integrating both GSH and fulvic acid recovery.

All scenarios were simulated under identical reactor conditions, with differences only in activated process units. The system was scaled up 20 times from the laboratory scale, equivalent to an input of 100 kg OPEFB per batch. The simulator automatically performed mass and energy balance calculations, equipment sizing, and economic evaluation.

Integration with experimental data

The process parameters used for simulation residence time, temperature, reagent concentration, and product yield were adopted from the mini pilot-scale experiments (5 kg feed basis). The RDS technology described herein was developed and validated through research collaboration between the Indonesian Oil Palm Research Institute (IOPRI) and BPDPKS-funded projects, but this technology is currently in the process of patent registration. This study therefore serves as the first formal documentation and modelling of the RDS process, bridging laboratory findings with industrial simulation outcomes.

Results and Discussion

Scale-up simulation of RDS OPEFB compost production

The scale-up process aims to model the escalating production scale from laboratory or smaller scale to industrial scale (Darmawan, 2024). The SuperPro Designer® software is used to analyse various technical and operational aspects in RDS compost production, such as raw material requirements, processing time, production capacity, as well as energy consumption and costs, which can be comprehensively analysed. The SuperPro Designer® software is used to analyse technical and operational aspects of RDS compost production, such as raw material requirements, process time, production capacity, energy consumption, and costs, which can be comprehensively analysed. The scale-up simulation was conducted to make the RDS compost production scale 20 times the size of the previous scale. This simulation was conducted using information on equipment and materials from the initial production scale, then adjusted to the availability of process units in the SuperPro Designer® system. The adjusted equipment and materials are shown in Table 1.

Table 1. Adjusted RDS compost production tools and materials

Equipment	Material
Tray drying 1	OPEFB (feedstock)
Shredding	-
Leaching	21% H_2O_2
Reactor	12.5% H_2O_2
Tray drying 2	-
Bioreactor	• *Trichoderma* sp. + *F. meliae* • Water

The equipment information in Table 1 has been adjusted to match the equipment designation in the SuperPro Designer® system. Furthermore, the production process flow was generated in the system based on the previous input. The production process flow is shown in Figure 1. The simulation indicated that 100 kg of OPEFB feedstock could generate 32.67 kg of RDS compost. The simulation also revealed the production duration for a one batch. The time required for a single batch was 45.01 hours. Detailed schedule and timeline of the process can be seen in Figure 2.

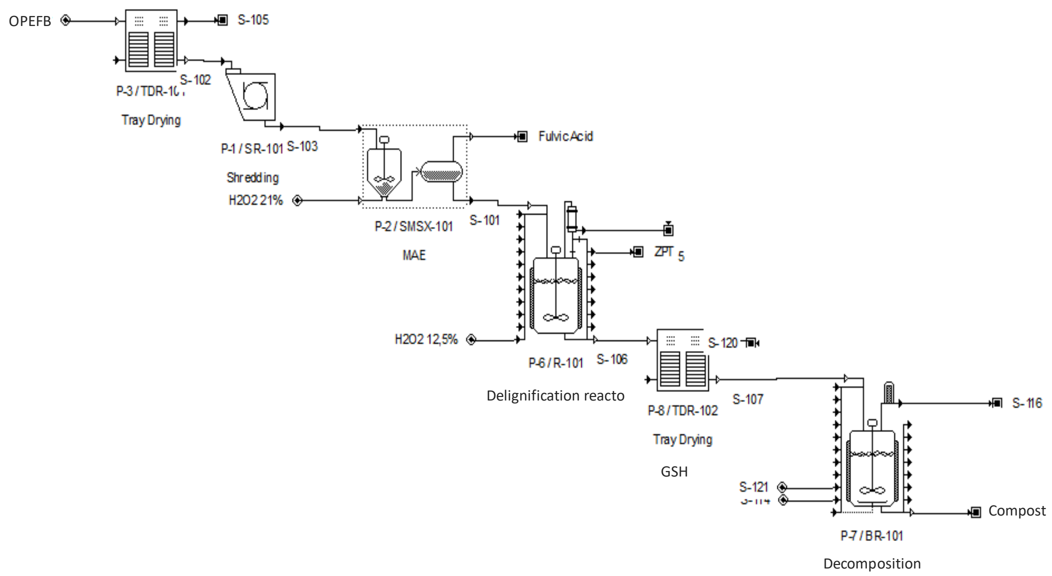

Figure 1. RDS compost production process flow simulated in SuperPro Designer®

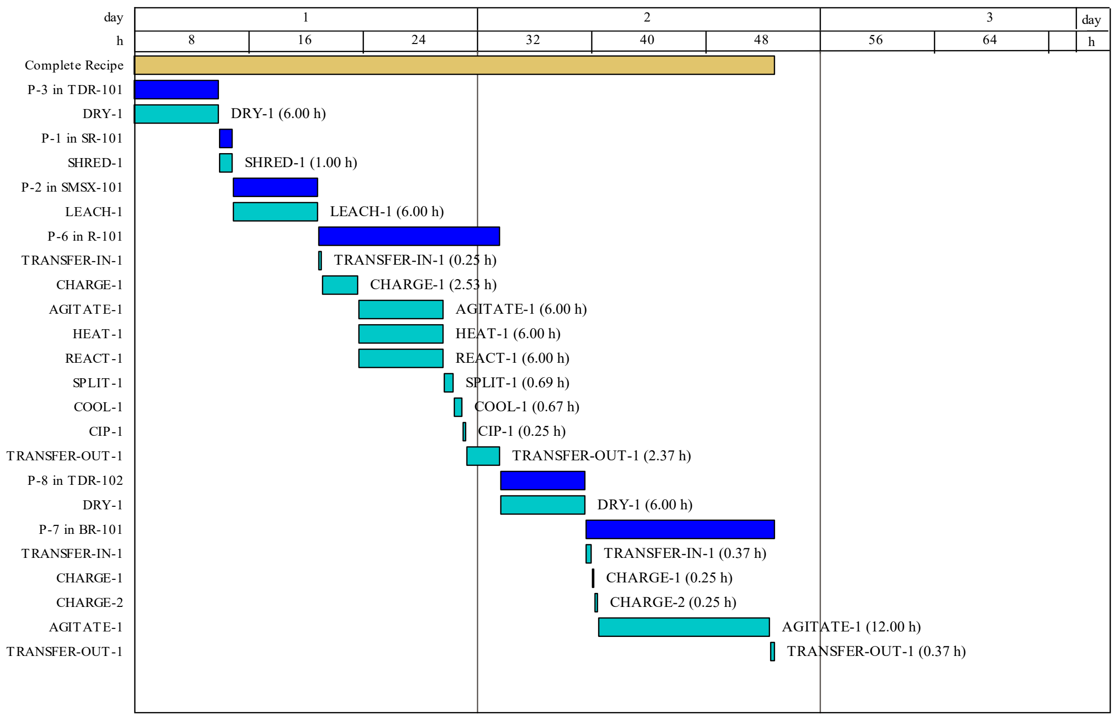

Figure 2. Simulated timeline of the RDS compost production process

Note:

: Main operations (delignification, composting, drying)

: Supporting operations (charging, preparation, transfer)

This simulation also generates detailed estimation of feedstock requirements based on the preferred production scale. This estimation includes annual materials requirements, the quantities required for each production batch, and the estimation of materials that needed to produce 1 kg of RDS compost. The feedstock requirements data from the simulation are shown in Table 2.

Techno-economic analysis

An economic analysis was conducted on three RDS compost production process scenarios. These include: 1) A production process that only takes into account RDS compost products; 2) A production process that considers RDS compost and GSH products; 3) A production process that also involves RDS compost, GSH, and fulvic acid products. The results of the economic analysis can be seen in Table 3.

According to Table 3, it can be observed that by increasing the diversity of products considered in the economic analysis, the profit gained will become higher. This occurred due to the fact that the wider the range of products generated from a single production process, the greater the value added obtained from the utilisation of the same resources. By producing not only RDS compost but also GSH and fulvic acid, the company can optimise the utilisation of raw materials and increase revenue through product diversification. Furthermore, relatively constant operational costs become more efficient when distributed across multiple products, thereby maximising profits. Therefore, the most profitable scenario is the compost, GSH, and fulvic acid product combination.

Table 2. Feedstock requirements based on simulation results

Material	Quantity (kg/yr)	Quantity (kg/batch)	Quantity (kg/kg RDS)
H_2O_2	566,956	952.87	29.17
OPEFB	53,669	90.20	2.76
Trichoderma sp. + *F. meliae*	1	0.01	0,01
Water	3,392,653	5,701.94	174.55
Total	4,013,279	6,745.01	206.48

Table 3. Economic analysis of RDS compost production process

Indicators	Scenario 1	Scenario 2	Scenario 3
Total capital investment	$ 6.045.000	$ 6.045.000	6.789.000 $
Operating cost	$ 3.594.000	$ 3.594.000	4.440.000 $
Main revenue	$ 38.000	$ 38.000	38.000 $
Other revenue	$ 0	$ 509.143	9.830.783 $/yr
Total revenue	$ 38.000	$ 547.000	9.868.000 $/yr
Batch size	32.67 kg RDS	32.67 kg RDS	32,67 kg RDS
Cost basis annual rate	19.470 kg RDS/yr	19.470 kg RDS/yr	19.437 kg RDS/yr
Unit production cost	$ 184,60/kg RDS	$ 184,60/kg RDS	228,46 $/kg RDS
Unit production revenue	$ 1,94/kg RDS	$ 28,09/kg RDS	507,72 $/kg RDS
Gross margin	-9.415,38 %	-557,15 %	55,00 %
Return on investment	-50,08%	-41,66%	68,67 %
Payback time	N/A	N/A	1,46 years
IRR (After Taxes)	N/A	N/A	41,08 %
NPV (at 7% Interest)	$ -28.606.000	$ -24.999.000	24.743.000 $

The most profitable scenario, where all products are included in the economic analysis, yields a gross margin of 55%. Gross margin is the difference between total revenue and total production costs (Erawan et al., 2023). A high gross margin indicates a feasible production process even before considering other costs such as taxes and interest. Additionally, a high Return on Investment (ROI) of 68.67% was obtained. This indicates that the capital invested in this product can generate profits quickly (Gómez et al., 2020).

Other insights include payback time, IRR, and NPV, which are 1.46 years, 41.08%, and 24,743,000 dollars, respectively. Net Present Value (NPV) is the present value of net income over a period (10 years) calculated using a defined discount factor. A project is considered financially feasible if the NPV value is positive. Meanwhile, the Internal Rate of Return (IRR) is the discount factor (df) that causes a business in a period to generate an NPV of 0, meaning it is neither profitable nor loss-making (break-even). If NPV = 0, then df is the IRR. A project is considered financially feasible if the IRR is higher than the determined discount factor rate. The payback period is the time required for a business to return the invested capital. The payback period is achieved when the accumulated cash flow is ≥ 0. According to the simulation process, it can be concluded that this technology is feasible to scale up to an industrial scale.

In previous studies, SuperPro Designer® has been widely applied to simulate and evaluate processes involving lignocellulosic feedstocks. For instance, Roussos et al. (2019) conducted a techno-economic assessment of isobutanol production from sugarcane vinasse, demonstrating the ability of the software to integrate chemical pretreatment, fermentation, and downstream separation within a single framework. Similarly, Erawan et al. (2023) used SuperPro Designer® to model the conversion of oil palm biomass into bioethanol, highlighting its potential for assessing mass and energy balances as well as production costs in biomass valorization. These examples underline the versatility of the software in evaluating complex bioprocesses for both liquid and solid feedstocks.

Further applications include the study of Karimah et al. (2021), who designed a furfural production plant using OPEFB as raw material. Utami et al. (2025) also employed SuperPro Designer® to evaluate OPEFB-based bioethanol production, concluding that the process could be technically viable but required optimization to achieve favorable economic indicators. These studies emphasize that while OPEFB offers abundant potential as a renewable feedstock for biofuel and chemical product, its conversion pathways often involve long processing times, complex downstream operations, and high capital costs.

Compared to these cases, the present study demonstrates that the RDS composting of OPEFB achieves superior performance, particularly in terms of process duration and economic viability. The combination of chemical delignification with H_2O_2 and microbial decomposition reduced the composting time to only 45 hours per batch, in contrast to the weeks or months often reported for fermentation or biofuel production. Moreover, the techno-economic indicators of the RDS process, including an ROI of 68.67%, a short payback period of 1.46 years, and a positive NPV of $24.7 million, were more favourable than those reported in many bioconversion process simulation studies. This suggests that integrating chemical and biological processes in solid waste management not only improves technical efficiency but also generates stronger financial outcomes, thereby expanding the scope of SuperPro Designer® applications into hybrid solid-state biomass conversion systems.

Conclusion

This study has showed that Rapid Decomposition System (RDS) technology has the capability to accelerate the process of converting oil palm empty fruit bunches (OPEFB) into compost both effectively and financially feasible. Scale-up simulations using SuperPro Designer® software indicate that 100 kg of OPEFB can produce 32.67 kg of compost in 45.01 hours per batch. Using the compost, GSH, and fulvic acid production scenario, this technology could generate 55% gross margin, 68.67% ROI, and payback period of 1.46 years. This technology is feasible and profitable for scaling up to an industrial scale based on the IRR and NPV indicators, which were 41.08% and $24,743,000, respectively.

Acknowledgements

Badan Pengelola Dana Perkebunan (BPDP) is highly appreciated for the research funding. This paper is a part of research funded by BPDP under contract No. PRJ-358/DPKS/2022. We also thank the Indonesian Oil Palm Research Institute – PT Riset Perkebunan Nusantara for supporting this research.

References

Aulia, W. D., Permana, A. T., Dimawarnita, F., & Faramitha, Y. (2024). Delignification of empty palm oil bunches with naoh on the quality of liquid organic fertilizer. *Journal of Agroindustrial Technology*, *34*(1), 47–54. https://doi.org/10.24961/j.tek.ind.pert.2024.34.1.47

Badan Pusat Statistik (BPS-Statistics Indonesia). (2024). *Indonesian Palm Oil Production in 2023*

Bentolila, M., Alshanski, I., Novoa, R., & Gilon, C. (2018). Optimization of chemical processes by the hydrodynamic simulation method (HSM). *ChemEngineering*, *2*(2), 1–8. https://doi.org/10.3390/chemengineering2020021

Civzele, A., Mezule, L. (2024). Isolation and screening of wood-decaying fungi for lignocellulolytic enzyme production and bioremediation processes. *Frontiers in Fungal Biology, 5,* 1494182. https://doi.org/10.3389/ffunb.2024.1494182

Darmawan, R. F. (2024). Kajian tekno ekonomi pemanfaatan konversi limbah biomassa refuse derived fuel (RDF) menjadi listrik melalui metode gasifikasi tiga tingkat dan mesin diesel dual fuel di Pulau Batam. [Institut Teknologi Sepuluh Nopember]. https://repository.its.ac.id/114325/

Dimawarnita, F., Maharani, K. Y., Faramitha, Y., Kalbuadi, D. N., Prakoso, H. T., Sari, I. P., Prasetyo, D., Sutanto, S., & Goenadi, D. H. (2024). Optimization of fulvic acids production from oil palm empty fruit bunches using microwave extractor. *Menara Perkebunan*, *92*(2), 141–152. https://doi.org/10.22302/iribb.jur.mp.v92i2.582

Dimawarnita, F., Andhayu, G. S., Faramitha, Y., & Mufidah, E. (2024). Production of crude enzyme from *Trichoderma* sp. *BIO Web of Conferences*, *99*. https://doi.org/10.1051/bioconf/20249902004

Erawan, F., Utami, A. R. I., Sugiwati, S., Maryana, R., Mel, M., & Darus, L. (2023). Potential development and economic analysis of bioethanol fabrication design from oil palm biomass with ionic liquid choline acetate using SuperPro Designer (SPD) software. *Journal of Physics: Conference Series*, *2673*(1). https://doi.org/10.1088/17426596/2673/1/012024

Gómez, J. A., Sánchez, Ó. J., & Correa, L. F. (2020). Techno-economic and environmental evaluation of cheesemaking waste valorization through process simulation using SuperPro Designer. *Waste and Biomass Valorization*, *11*(11), 6025–6045. https://doi.org/10.1007/s12649-019-00833-4

Harahap, A. F., Hidayat, M., & Suhanan. (2021). Utilization of oil palm empty fruit bunches as mulch in community owned oil palm plantations (case study in Simardona Village, North Sumatra). *ASEAN Journal of System Engineering*, 5(2). http://journal.ugm.ac.id/index.php/ajse

Haryanti, A., Norsamsi, Sholiha, P. S. F., & Putri, N. P. (2014). Studi pemanfaatan limbah padat kelapa sawit. *Konversi*, *3*(2), 57-66. https://doi.org/10.20527/k.v3i2.161

Howard, J. R., Amidon, T. E., Liu, S., & Wood, C. D. (2013). *United States Patent* (Patent US00861828OB2)

Intelligen, Inc. (2025). *SuperPro Designer Overview*. https://www.intelligen.com/products/superpro-overview/

Iswahyudi, H., & Iskandar, M. D. (2023). Content of macro nutrition of fiber compost and oil palm empty fruit bunch (*Elaeis guineensis Jacq*.). *EnviroScienteae*, *19*(1), 9-13. http://dx.doi.org/10.20527/es.v19i1.15731

Karimah, I., Suyuditomo, G., Harahap, A. F. P., Ramadhan, M. Y. A., Panjaitan, J. R. H., Sahlan, M., Hermansyah, H., & Gozan, M. (2021). Techno-economic analysis of furfural production with various pretreatment of oil palm empty fruit bunches using SuperPro Designer. *IOP Conference Series: Earth and Environmental Science*, *749*(1). https://doi.org/10.1088/17551315/749/1/012042

Karunarathna, S. C., Patabendige, N. M., Kumla, J., Hapuarachchi, K. K., & Suwannarach, N. (2025). The bioactive compounds, beneficial medicinal properties, and biotechnological prospects of *Fomitopsis*: a comprehensive overview. *Frontiers in Cellular and Infection Microbiology*, *15*(1534617). https://doi.org/10.3389/fcimb.2025.1534617

Listyarini, D., Tampubolon, G., & Widodo, F. W. (2024). Pengaruh kompos tandan kosong kelapa sawit terhadap beberapa sifat kimia tanah bekas tambang batubara dan pertumbuhan *Falcataria moluccana* (miq.) barneby & grimes. *Fruitset Sains: Jurnal Pertanian Agroteknologi*, *12*(5), 309-318. https://doi.org/10.35335/fruitset.v12i5.5855

Mansyur, N. I., Pudjiwati, E. H., & Murtilaksono, A. (2021). *Pupuk dan Pemupukan*. Syiah Kuala University Press

Nabila, R., Hidayat, W., Haryanto, A., Hasanudin, U., Iryani, D. A., Lee, S., Kim, S., Kim, S., Chun, D., Choi, H., Im, H., Lim, J., Kim, K., Jun, D., Moon, J., & Yoo, J. (2023). Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization. *Renewable and Sustainable Energy Reviews*, *176*. https://doi.org/10.1016/j.rser.2023.113193

Nurrohmanysah, R., Indriyani, A., Ekaliana, E., & Telaumbanua, M. (2019). Microcontroller-based liquid fertilizer developer from palm empty fruit bond waste. *Agroteknika*, *2*(2), 51–58.https://doi.org/10.32530/agroteknika.v2i2.43

Pramana, A., Hamzah, A., Haitami, A., & Okalia, D. (2021). Quality analysis of "Kosmos" *OPEFB* compose using selulolitic microorganism. *Agrointek*, *15*(3), 839–844. https://doi.org/10.21107/agrointek.v15i3.10149

Roussos, A., Misailidis, N., Koulouris, A., Zimbardi, F., & Petrides, D. (2019). A feasibility study of cellulosic isobutanol production-process simulation and economic analysis. *Processes*, *7*(10). https://doi.org/10.3390/pr7100667

Sakiah, S., Arfianti, D., Silalahi, A. B., & Lesmana, I. (2024). Pemanfaatan *Trichoderma* sp dan *Aspergillus* sp. dalam pengomposan tandan kosong kelapa sawit. *Tabela Jurnal Pertanian Berkelanjutan*, *2*(1), 37-43. https://doi.org/10.56211/tabela.v2i1.459

Sentana, S., Suyanto, Subroto, M. A., Suprapedi & Sudiyana, (2010). Pengembangan dan pengujian inokulum untuk pengomposan limbah tandan kosong kelapa sawit. *Jurnal Rekayasa Proses*, *4*(2), 35

Utami, A. R. I., Sugiwati, S., Maryana, R., Darus, L., Mel, M., Maulidin, I., Erawan, F., Yupaldi, N., & Zhafran, A. L. (2025). Predictive modelling of ethanol production from biomass pretreated with ionic liquids using SuperPro Designer. *Journal of Physics: Conference Series*, *2942*(1). https://doi.org/10.1088/17426596/2942/1/012048

Zaman, N. Z. I. S., Abbas, A. R., Zainal, M. F., Quek, A., Ata, W. N. S. W., Mohd Yapandi, M. F. K., & Ibrahim, Z. F. (2024). Assessing the environmental impact of empty fruit bunches for electricity generation in Malaysia: A life cycle perspective. *IOP Conference Series: Earth and Environmental Science*, *1372*(1). https://doi.org/10.1088/17551315/1372/1/012057