

OPTIMIZATION OF LINGZHI MUSHROOM (*GANODERMA LUCIDUM*) MEDIA USING OIL PALM WASTE FOR FUNCTIONAL FOOD

Muh. Ichwan K*, Herman Nursaman, Dian Mirnawaty Sultan

^{1,2,3}Universitas Islam Makassar

*E-mail: muhichwank.dty@uim-makassar.ac.id

Received, 21st October 2025; Revised, 09th January 2026;

Accepted, 20th January 2026

ABSTRACT

Oil palm stem waste is an environmental problem that holds great potential as an alternative substrate for mushroom cultivation due to its high lignocellulose content. Its utilization can replace the increasingly scarce sawdust while supporting the concept of a green economy. This study aimed to formulate a cultivation medium for *Ganoderma lucidum* based on oil palm stem waste through fermentation optimization using EM4 and molasses, to produce an eco-friendly medium that supports mushroom growth and functional food development. The research methods included substrate characterization (C/N ratio, lignin, phenol, moisture), fermentation optimization using Response Surface Methodology (RSM) with variations of EM4 dosage (1–5%), molasses concentration (5–15%), and fermentation duration (7–21 days). The optimized fermented substrate was then formulated into Baqlog medium (75% fermented substrate, 20% rice bran, 3% agricultural lime). Growth performance of *G. lucidum* was tested on Baqlog medium, followed by phytochemical analysis. The results showed that the optimal fermentation condition was at 3% EM4, 10% molasses, and 14 days, reducing lignin from 28.5% to 14.8%, phenol from 1.6% to 0.45%, and improving the C/N ratio from 44.2 to 28.5. Mycelial colonization was faster (18 days) compared to the control (34 days), with higher biomass (7.2 g/baglog, increased by 36%). Phenolic content also increased from 0.7 mg/g to 2.5 mg/g. In conclusion, fermentation of oil palm stem waste produced an effective medium that accelerated colonization, increased biomass, and enriched the bioactive content of *G. lucidum*.

Keywords: *Ganoderma lucidum*; *oil_palm_stem_waste*; *fermentation*; *cultivation_medium*; *functional_food*

INTRODUCTION

Oil palm is one of Indonesia's strategic commodities. In South Sulawesi Province, the total oil palm plantation area reaches 43,493 hectares, supported by eight processing industries with a combined capacity of 1.53 million tons per year. The People's Oil Palm Replanting Program (PSR) in 2024 targets the revitalization of 8,421 hectares, potentially generating around 1.07 million oil palm trunk wastes (136 trees/ha). If not utilized, this waste can cause environmental pollution, increase carbon

emissions, and contaminate the soil due to the presence of toxic compounds such as phenols (Awoh et al., 2023).

Oil palm trunk waste has a high lignocellulose content (45–55%), making it a promising alternative substrate for mushroom cultivation. Its utilization is crucial given the declining availability of sawdust (Sudirman et al., 2011). Several studies have shown that oil palm wastes such as empty fruit bunches and fronds can be used as growth media for oyster mushrooms (*Pleurotus* sp.) and paddy straw mushrooms (*Volvariella volvacea*), achieving 1.5–1.9 times faster growth compared to conventional substrates (Aubrey et al., 2022; Triyono et al., 2019). However, research on the use of oil palm trunk waste as a substrate for high-value functional mushrooms such as *Ganoderma lucidum* remains limited.

The genus *Ganoderma* has a dual nature: *Ganoderma boninense* is known as a pathogen damaging oil palm, while *Ganoderma lucidum* (Lingzhi) has high economic value due to its bioactive compounds with antioxidant, immunomodulatory, and anticancer properties (Hendri, 2016). The export market price of *G. lucidum* products can reach IDR 3 million per kilogram. However, *Ganoderma*-based products in Indonesia are still dominated by imports, indicating a lack of local innovation development (Kadir et al., 2024).

Utilizing oil palm trunk waste as a substrate for *G. lucidum* offers a strategic opportunity to transform an ecological problem into an economic resource. Through fermentation technology using EM4 and molasses, the lignin and phenol contents can be reduced and the C/N ratio improved, making the substrate more suitable for mushroom growth (Hidayati & Baristand, 2015). Therefore, this research is important to support people's economy, food security, and the development of functional food based on mushrooms.

LITERATURE REVIEW

Utilization of Agricultural and Plantation Waste as Mushroom Cultivation Media

Agricultural and plantation residues have become important raw materials for sustainable and low-cost mushroom cultivation. Among these, oil palm waste is abundant in Indonesia and contains a high proportion of lignocellulose—comprising approximately 40–55% cellulose, 25–30% hemicellulose, and 20–30% lignin (Sudirman et al., 2011). However, the high lignin and phenolic contents limit its direct use as a fungal substrate due to its recalcitrant nature. Thus, pretreatment or fermentation processes are required to degrade these complex polymers, increase nutrient availability, and improve substrate porosity.

Studies have highlighted that the valorization of oil palm waste supports both waste reduction and circular bioeconomy efforts. According to Awoh et al. (2023), efficient utilization of oil palm residues can significantly reduce carbon emissions and mitigate environmental pollution caused by unmanaged biomass accumulation.

Application of Oil Palm Waste in Edible Mushroom Cultivation

The use of oil palm by-products such as empty fruit bunches, fronds, and fiber for mushroom cultivation has been successfully explored. Aubrey et al. (2022) demonstrated that oyster mushrooms (*Pleurotus ostreatus*) cultivated on oil palm residues showed 1.5–1.9 times faster mycelial growth than on conventional sawdust

substrates. Similarly, Triyono et al. (2019) found that straw mushrooms (*Volvarella volvacea*) grown on oil palm empty fruit bunches achieved higher yields and faster fruiting. These findings indicate that oil palm waste provides an effective and low-cost growth medium alternative.

In addition, Hendri (2016) reported that supplementing oil palm-based substrates with nitrogen-rich materials such as rice bran can further enhance growth rates, mycelial density, and biological efficiency.

Biological Fermentation to Improve Substrate Quality

Fermentation using microbial consortia such as Effective Microorganisms (EM4), combined with molasses as a carbon source, plays a crucial role in improving the biological and chemical quality of the substrate. This process involves the decomposition of lignin, phenols, and other inhibitory compounds through microbial enzymes such as laccase and lignin peroxidase. As a result, the C/N ratio is optimized within the ideal range of 25–35, enhancing fungal nutrient absorption (Hidayati & Baristand, 2015).

Moreover, the fermentation process increases substrate moisture retention and porosity, both of which are essential for effective mycelial colonization and gas exchange. Biological pretreatment is thus considered an eco-friendly alternative to chemical delignification methods and is particularly suitable for community-scale mushroom production.

Potential and Economic Value of *Ganoderma lucidum* (Lingzhi Mushroom)

Ganoderma lucidum, commonly known as Lingzhi mushroom, has long been recognized for its medicinal and functional food properties. It contains various bioactive compounds such as triterpenoids, polysaccharides, phenolic acids, and peptides, which exhibit antioxidant, immunomodulatory, and anticancer activities (Hendri, 2016).

Globally, the economic value of *G. lucidum* products is high, with export prices reaching up to IDR 3 million per kilogram. However, Indonesia still relies heavily on imported *Ganoderma* products, reflecting limited local innovation and cultivation technology (Kadir et al., 2024). Expanding domestic production through locally available and sustainable media such as oil palm trunk waste could therefore provide significant socio-economic benefits.

Research Gaps and Opportunities

Although many studies have examined the use of oil palm residues for cultivating edible mushrooms, research on high-value functional mushrooms like *Ganoderma lucidum* using oil palm trunk waste remains limited. The dual nature of the *Ganoderma* genus further underscores this potential—*Ganoderma boninense* is a destructive pathogen in oil palm plantations, while *G. lucidum* can convert the same biomass waste into valuable functional food resources.

Consequently, optimizing fermentation parameters such as EM4 dosage, molasses concentration, and incubation duration using Response Surface Methodology (RSM) presents a promising research direction. This approach aligns with sustainable development goals (SDGs), particularly those focusing on responsible production, waste reduction, and rural economic empowerment.

RESEARCH METHODOLOGY

Time and Location

The research was conducted during the first implementation year (2024–2025) at the university laboratory and the oil palm trunk waste collection site located in Pinrang Regency, South Sulawesi, Indonesia.

Tools and Materials

The primary material used in this study was oil palm trunk waste, which was fermented using EM4 (Effective Microorganisms) and molasses as an additional carbon source. To support the formulation of the cultivation medium, rice bran was added as an additional nitrogen source and agricultural lime was used to balance the pH. Heat-resistant plastic bags were used as containers for making baglog (mushroom growing blocks).

The equipment employed included an autoclave for substrate sterilization, a digital scale, a hydraulic press for baglog formation, a drying oven, a spectrophotometer for phenol content analysis, as well as inoculation and incubation tools for mushroom cultivation. The availability of these tools and materials enabled a comprehensive research process encompassing substrate characterization, fermentation, cultivation media formulation, and fungal growth analysis (Sudirman et al., 2011; Hidayati & Baristand, 2015).

Research Procedures

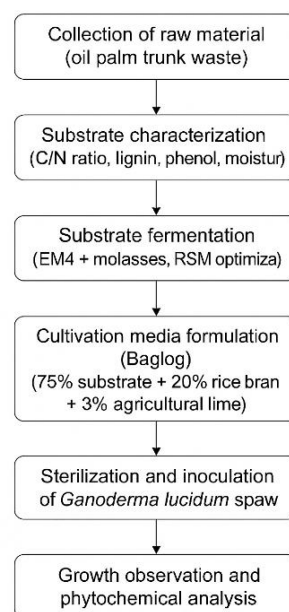


Figure 1. Flow diagram of research methodology steps

Raw Material Collection (Oil Palm Trunk Waste)

The study began with the collection of oil palm trunk waste from replanting areas located in North Luwu and East Luwu Regencies. This raw material was selected due to its abundant availability and high lignocellulose content, though it required further processing to make it suitable as a mushroom cultivation substrate.

Substrate Characterization (C/N Ratio, Lignin, Phenol, Moisture)

Before fermentation, the chemical properties of the substrate were analyzed. The carbon-to-nitrogen (C/N) ratio was determined using the Walkley–Black and Kjeldahl

methods, lignin content was measured using the Klason method, phenolic compounds were quantified using the Folin–Ciocalteu spectrophotometric method, and moisture content was measured by gravimetric analysis. These results served as the basis for fermentation optimization (Aubrey et al., 2022).

Substrate Fermentation (EM4 + Molasses, RSM Optimization)

The substrate was fermented using microorganisms contained in EM4 with the addition of molasses as a carbon source. The fermentation process followed a Response Surface Methodology (RSM) experimental design, applying variations in EM4 dosage, molasses concentration, and fermentation duration. This stage aimed to reduce lignin and phenol levels and improve the C/N ratio to make the substrate more suitable for fungal growth (Triyono et al., 2019).

Cultivation Media Formulation (Baglog)

The fermented substrate was then formulated into baglog-type cultivation media, consisting of 80% fermented substrate, 17% rice bran (as an additional nitrogen source), and 3% agricultural lime (for pH balance). The mixture was compacted into heat-resistant plastic bags measuring 18 × 35 cm.

Sterilization and Inoculation of *Ganoderma lucidum*

The formulated baglogs were sterilized using an autoclave at 100°C for 4 hours. After cooling, the baglogs were aseptically inoculated with *Ganoderma lucidum* spawn and then incubated under controlled environmental conditions.

Growth Observation and Phytochemical Analysis

The final stage involved observing mushroom growth performance, including mycelial colonization speed, biomass yield, and adaptability of *G. lucidum* to the fermented substrate. Additionally, a phytochemical analysis was conducted to measure the concentration of bioactive phenolic compounds responsible for antioxidant activity (Kadir et al., 2024).

RESULTS AND DISCUSSION

The utilization of oil palm waste as a mushroom cultivation medium has been widely studied and has shown great potential in optimizing fungal growth. For instance, a study on the Technology Transfer for the Utilization of Oil Palm Fronds demonstrated that oil palm fronds, which were previously considered waste, can be used as an alternative substrate for oyster mushroom cultivation, thereby contributing valuable insights into the development of a more economical and easily accessible growth medium.

Initial Characterization of Oil Palm Trunk Waste Substrate

Research on the growth of white oyster mushrooms (*Pleurotus ostreatus*) using a medium containing 99% oil palm fronds showed optimal mycelial growth with significant differences in colonization time, supporting the efficiency of oil palm waste as a mushroom substrate.

Chemical characterization of oil palm trunk waste for *Ganoderma lucidum* using the Walkley–Black and Kjeldahl methods showed a carbon (C) content of 48.6% and a

nitrogen (N) content of 1.1%, resulting in an initial C/N ratio of 44.2, indicating that the substrate was resistant to decomposition. According to literature, the ideal C/N ratio for mushroom growth ranges between 25–35. Lignin analysis using the Klason method showed a lignin content of 28.5%, while phenol testing using the Folin–Ciocalteu spectrophotometric method yielded a phenol concentration of 1.6%. The initial moisture content was measured at 55%. These data indicate the necessity of a fermentation process to reduce lignin and phenol contents and to improve the C/N ratio to support the growth of *Ganoderma lucidum*.

Optimization of Substrate Fermentation Using EM4 and Molasses

The fermentation of waste substrate using ligninolytic enzyme-producing microorganisms and EM4 as an inoculum has been proven to reduce lignin and phenol contents, thereby improving substrate quality and accelerating fungal growth. Studies on fermented oil palm frond baglogs have demonstrated that biological fermentation is an effective method for degrading complex compounds in waste materials.

The fermentation experiment was designed using the Response Surface Methodology (RSM) with variations in EM4 dosage (1%, 3%, 5%), molasses concentration (5%, 10%, 15%), and fermentation duration (7, 14, and 21 days). Post-fermentation analysis showed a significant reduction in lignin content to 14.8% ($p < 0.05$) under optimal conditions of 3% EM4, 10% molasses, and 14 days of fermentation. The phenol content decreased to 0.45%, and the C/N ratio improved to 28.5, meeting the standard range for mushroom cultivation media. The substrate moisture content was maintained at approximately 65% after fermentation.

Table 1. Summary of Key Parameters Before and After Fermentation Under Optimal Conditions

Parameter	Before Fermentation	After Optimal Fermentation	Reduction (%)
Lignin (%)	28.5	14.8	48.07
Phenol (%)	1.6	0.45	71.87
C/N Ratio	44.2	28.5	35.52
Moisture (%)	55	65	–

The comparison of substrate parameters before and after fermentation shows significant changes. The lignin content decreased from 28.5% to 14.8%, while the phenol concentration was drastically reduced from 1.6% to 0.45%. The initially high C/N ratio (44.2) was successfully lowered to 28.5, approaching the ideal range for fungal growth. In addition, the moisture content increased from 55% to 65%, making the substrate conditions more favorable for mycelial development. These changes indicate that the fermentation process effectively improved the quality of oil palm waste substrate as a cultivation medium.

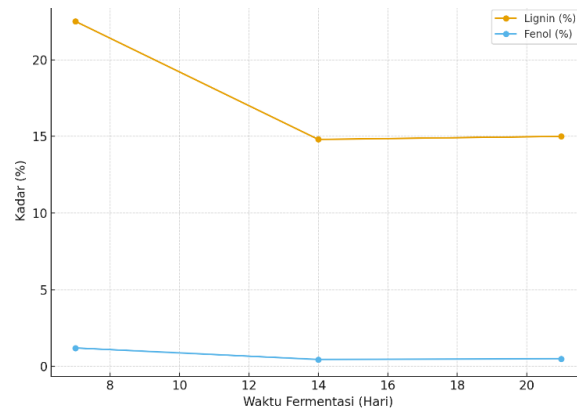


Figure 2. Trends in lignin and phenol reduction during fermentation

Figure 2 shows the trend of lignin and phenol reduction at different fermentation durations, indicating that the most optimal decrease occurred on the 14th day, while after the 21st day, the lignin and phenol values remained relatively stable. This suggests that a 14-day fermentation period is sufficient to achieve the best substrate quality without the need for extended fermentation time.

Formulation and Testing of Baqlog Mushroom Cultivation Media

The formulation of the Baqlog cultivation medium used 75% fermented oil palm waste substrate, 20% rice bran as an additional nitrogen source, and 3% agricultural lime for pH adjustment. The medium was sterilized using an autoclave at 100°C for 4 hours and molded into baglogs measuring 18 cm × 35 cm.



Figure 3. Process of preparing mushroom cultivation media (baglog) based on oil palm trunk waste.

Figure 3 illustrates the process of preparing mushroom cultivation media (baglog) using oil palm trunk waste. The process includes mixing the fermented substrate, adding rice bran and agricultural lime, and sterilizing the medium before inoculation with mycelium. The physical quality test of the medium showed a density of 0.45 g/cm³, which is optimal for aeration, water absorption capacity of 65% after soaking, and good structural stability, as the medium remained intact during handling.

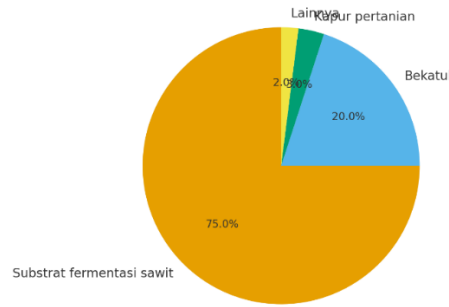


Figure 4. Pie chart of Baqlog medium composition.

Figure 4 provides a visual illustration of the composition of the Baqlog medium, showing the dominance of fermented oil palm substrate supplemented with rice bran as a nitrogen source and agricultural lime as a pH stabilizer.

Growth of Ganoderma lucidum on the Formulated Medium

The cultivation of *Ganoderma lucidum* on the Baqlog medium showed accelerated mycelial colonization, with an average growth time of 18 days, compared to the control substrate (sawdust), which required an average of 34 days. The mycelial biomass reached 7.2 grams per baglog on the 25th day, which was 36% higher than the control. This rapid mycelial growth is presumed to result from the fermented substrate’s high soluble nutrient content and low phenolic toxicity.

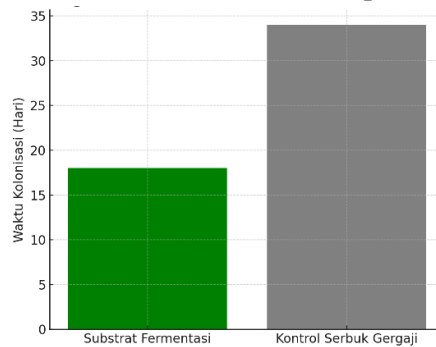


Figure 5. Comparison graph of mycelium colonization time in fermentation and control media.

Figure 5 presents a graph comparing the mycelial colonization time between the fermented and control media, showing a striking difference. *Ganoderma lucidum* grown on the fermented Baqlog medium required only 18 days for full colonization, whereas the sawdust control took 34 days. Thus, the fermented substrate was able to accelerate the colonization process nearly twice as fast.

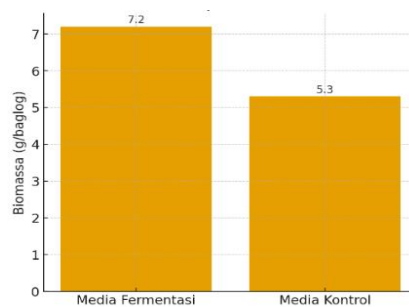


Figure 6. Mycelial Biomass in Fermentation and Control Media

This finding is consistent with Figure 6, which shows the mycelial biomass graph, where the fermented medium produced an average of 7.2 g/baglog, which is 36% higher than the control (5.3 g/baglog). This increase indicates that the fermented substrate provides more accessible nutrients for the fungus.



Figure 7. Initial conditions of *Ganoderma lucidum* mycelium in Baqlog fermentation media.

Figure 7 shows the initial condition of *Ganoderma lucidum* mycelium in Baqlog fermentation media. The mycelium can be seen starting to grow evenly on the substrate surface after several days of inoculation.



Figure 8. *Ganoderma lucidum* mycelial development during colonization of the fermentation medium.

Figure 8 shows the development of *Ganoderma lucidum* mycelial growth during colonization of the fermentation medium. The mycelium grew rapidly and filled the baglog in an average of 18 days, shorter than the control.

Phytochemical Analysis of Mushroom Growing Media

Phytochemical tests of the media showed an increase in the content of antioxidant phenolic compounds of 2.5 mg/g of media, compared to the original substrate (0.7 mg/g). This indicates that the fermented media can increase the bioactive content, potentially supporting the functional food properties of *Ganoderma lucidum*.

Effect of Fermentation on Chemical Characteristics of Oil Palm Trunk Waste

The significant reduction in lignin content from 28.5% to 14.8% following fermentation indicates that the EM4–molasses system effectively enhanced lignocellulosic degradation. This result is consistent with the findings of Liu et al. (2021), who reported that microbial consortia containing ligninolytic fungi and bacteria are capable of producing enzymes such as laccase, manganese peroxidase, and lignin peroxidase, which accelerate lignin depolymerization in oil palm biomass.

The decrease in lignin content improves cellulose accessibility, thereby increasing substrate digestibility for fungal mycelium.

In addition to lignin degradation, phenolic compounds were reduced by 71.87%, from 1.6% to 0.45%. Phenols are known to inhibit fungal enzyme activity and mycelial growth. According to Ma et al. (2019), unmanaged oil palm waste contains high levels of phenolic compounds that can cause phytotoxic effects and slow microbial colonization. The sharp reduction in phenol concentration observed in this study confirms that biological fermentation is an effective detoxification strategy, making the substrate more suitable for *Ganoderma lucidum* cultivation.

The improvement of the C/N ratio from 44.2 to 28.5 further supports the effectiveness of the fermentation process. An optimal C/N ratio is critical for balancing carbon as an energy source and nitrogen for protein synthesis in fungal cells. Zhang et al. (2014) reported that mushroom substrates with a C/N ratio between 25 and 35 promote faster mycelial colonization and higher biological efficiency, which aligns well with the results obtained in this study.

Influence of Fermented Substrate on Mycelial Growth and Biomass Production

The accelerated mycelial colonization of *Ganoderma lucidum* on fermented oil palm trunk waste (18 days) compared to the control sawdust medium (34 days) demonstrates the superior quality of the optimized substrate. This finding is in agreement with Aubrey et al. (2022), who observed that oil palm residues subjected to biological treatment supported significantly faster mycelial expansion in *Pleurotus ostreatus* due to improved nutrient availability and reduced structural resistance.

The 36% increase in mycelial biomass (7.2 g/baglog) further indicates that the fermented substrate provided a more favorable growth environment. Chen et al. (2019) emphasized that oil palm-based substrates, when properly treated and supplemented with nitrogen sources such as rice bran, can outperform conventional sawdust media in terms of biomass yield. The enhanced biomass observed in this study can be attributed to the synergistic effect of lignin degradation, improved C/N ratio, and reduced phenolic toxicity.

Enhancement of Bioactive Phenolic Compounds and Functional Food Potential

The increase in phenolic content from 0.7 mg/g to 2.5 mg/g in the fermented growing media suggests that substrate fermentation not only improves growth performance but also enhances the functional quality of *Ganoderma lucidum*. According to Chen et al. (2019), phenolic compounds in *Ganoderma* species are closely associated with antioxidant and immunomodulatory activities, which are key attributes of functional foods. Furthermore, Chang & Wasser (2017) highlighted that the nutritional and medicinal value of edible mushrooms is strongly influenced by substrate composition and pretreatment methods. The higher phenolic content observed in this study indicates that oil palm trunk waste, when biologically fermented, can serve as a strategic medium for producing high-value functional mushrooms with enhanced health benefits.

CONCLUSION

This research demonstrates that oil palm trunk waste can be utilized as a potential alternative substrate for cultivating *Ganoderma lucidum*. Through a fermentation process using EM4 and molasses, the lignin and phenol content in the substrate can be significantly reduced, while the C/N ratio is successfully improved to within the ideal range for fungal growth. The formulation of a growing medium in the form of baglogs with a composition of 75% fermented substrate, 20% rice bran, and 3% agricultural lime has been shown to support accelerated mycelial colonization, increased biomass, and improved media stability.

In addition to supporting faster growth, the fermented oil palm waste-based medium also increases the content of phenolic compounds with antioxidant activity, enhancing the functional value of *G. lucidum*. These results confirm that the utilization of oil palm trunk waste not only contributes to plantation waste management but also offers economic and health prospects through the development of mushroom-based functional foods. Therefore, this innovative, environmentally friendly growing medium has the potential for broader application on an industrial scale and for community empowerment.

ACKNOWLEDGMENTS

This research was funded by the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia through the Beginner Lecturer Research (PDP) grant scheme. We express our deepest gratitude for the financial support provided, which enabled the successful implementation and completion of this study.

REFERENCES

- Aubrey, M. L. L., Chin, C. F. S., Seelan, J. S. S., Chye, F. Y., Lee, H. H., & Rakib, M. R. M. (2022). Conversion of oil palm by-products into value-added products through oyster mushroom (*Pleurotus ostreatus*) cultivation. *Horticulturae*, 8(11), 1040. <https://doi.org/10.3390/horticulturae8111040>
- Awoh, E. T., Kiplagat, J., Kimutai, S. K., & Mecha, A. C. (2023). Current trends in palm oil waste management: A comparative review of Cameroon and Malaysia. *Heliyon*, 9(11), e21410. <https://doi.org/10.1016/j.heliyon.2023.e21410>
- Chang, S. T., & Wasser, S. P. (2017). The role of culinary-medicinal mushrooms on human welfare with a pyramid model for human health. *International Journal of Medicinal Mushrooms*, 19(7), 603–610. <https://doi.org/10.1615/IntJMedMushrooms.2017020869>
- Chen, S., Oh, S. R., Phung, S., Hur, G., Ye, J. J., Kwok, S. L., Shrode, G. E., Belury, M., Adams, L. S., & Williams, D. (2019). Anti-aromatase activity of phytochemicals in white button mushrooms (*Agaricus bisporus*). *Cancer Research*, 66(24), 12026–12034. <https://doi.org/10.1158/0008-5472.CAN-06-2966>
- El-Ramady, H., Abdalla, N., Badgar, K., Llanaj, X., Törös, G., Hajdú, P., Eid, Y., & Prokisch, J. (2022). Edible mushrooms for sustainable and healthy human food: Nutritional and medicinal attributes. *Sustainability*, 14(9), 4941. <https://doi.org/10.3390/su14094941>

- Hendri, Y. (2016). Pengaruh kombinasi substrat tandan kosong kelapa sawit dengan serbuk gergaji untuk mempercepat pertumbuhan tubuh buah jamur tiram putih (*Pleurotus ostreatus*). *Jurnal Agroteknologi Tropika*, 5(1), 45–52.
- Hidayati, M. R., & Baristand, A. (2015). Pemanfaatan serat tandan kosong kelapa sawit sebagai media pertumbuhan jamur tiram putih (*Pleurotus ostreatus*). *Jurnal Industri Pontianak*, 9(2), 112–120.
- Isroi, Millati, R., Syamsiah, S., Niklasson, C., Cahyanto, M. N., Lundquist, K., & Taherzadeh, M. J. (2011). Biological pretreatment of lignocelluloses with white-rot fungi and its applications: A review. *BioResources*, 6(4), 5224–5259.
- Kadir, M. I., Husain, N. P., & Nur, R. A. (2024). Peningkatan kapasitas budidaya jamur menggunakan limbah sagu pada masyarakat Kampung Sabron – Kabupaten Jayapura. *Jurnal Pengabdian Sosial*, 1(3), 93–101. <https://doi.org/10.59837/fnycvp29>
- Liu, Y., Sun, J., Rao, S., Su, Y., Yang, Y., & Yang, X. (2021). Antioxidant activity and phenolic compounds of *Ganoderma lucidum* cultivated on different substrates. *Journal of Food Composition and Analysis*, 96, 103720. <https://doi.org/10.1016/j.jfca.2020.103720>
- Ma, J., Yang, H., Basile, M. J., & Kennelly, E. J. (2019). Analysis of triterpenoids from *Ganoderma lucidum* using LC-MS and their biological activities. *Journal of Agricultural and Food Chemistry*, 67(5), 1281–1290. <https://doi.org/10.1021/acs.jafc.8b06205>
- Paterson, R. R. M. (2006). *Ganoderma*—A therapeutic fungal biofactory. *Phytochemistry*, 67(18), 1985–2001. <https://doi.org/10.1016/j.phytochem.2006.07.004>
- Sudirman, L. I., Sutrisna, A., Listiyowati, S., Fadli, L., & Tarigan, B. (2011). The potency of oil palm plantation wastes for mushroom production. *Jurnal Bioteknologi Perkebunan*, 2(1), 15–22.
- Triyono, S., Haryanto, A., Telaumbanua, M., Dermiyati, Lumbanraja, J., & To, F. (2019). Cultivation of straw mushroom (*Volvariella volvacea*) on oil palm empty fruit bunch growth medium. *International Journal of Recycling of Organic Waste in Agriculture*, 8(4), 381–392. <https://doi.org/10.1007/s40093-019-0259-5>
- Zhang, Y., Geng, W., Shen, Y., Wang, Y., & Dai, Y. (2014). Edible mushroom cultivation for food security and rural development in China: Bio-innovation, technologies and applications. *Sustainability*, 6(5), 2961–2973. <https://doi.org/10.3390/su6052961>