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Growth Improvement of Palm Oil Seedling using Biochar from Oil Palm Empty Fruit Bunch and Rubber Wood

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ABSTRACT

Agricultural wastes biochar can be used to support the growth of oil palm seedlings. This study aims to assess the effectiveness of biochar pellets made from oil palm empty fruit bunches (OPEFB) and rubber wood wastes on the growth of oil palm seedlings. The research was conducted in the greenhouse using a factorial complete randomized design with two treatment factors, namely the type of biochar pellets (OPEFB and rubber wood) and doses of 0%, 5%, 10% with 10 replications. Observation included plant height, stem diameter, number of leaves, and total dry weight. The results showed that biochar pellet application had a significant effect on plant growth, especially at a 10% dose, which increased plant height, stem diameter, number of leaves, and dry weight compared with the control. The 10% dose of OPEFB biochar pellet produced a plant height of 21.4 cm, stem diameter of 3.64 cm, and number of leaves of 8 strands, while the same dose of rubber wood biochar pellet produced a height of 15.67 cm, diameter of 3.64 cm, and number of leaves of 6.67 strands. OPEFB biochar pellet showed higher results than rubber wood biochar, but at the same dose, the difference is minor. These results indicate that biochar pellets from agricultural waste have the potential to effectively support the growth of oil palm seedlings in an environmentally friendly manner.

1. INTRODUCTION

The availability of fertile and productive soil that can support plant growth and is free of contaminants is a major factor in developing a healthy and environmentally friendly agricultural sector (Aji *et al*., 2019). The agricultural sector is the mainstay of the livelihood of the Indonesian population. However, in general, farmers use chemical fertilizers to fertilize the soil because they are more practical and do not need to be made (Dewi & Afrida, 2022). On the other side, excessive use of chemical fertilizers results in the declining of soil organic matter (SOM), thereby decreasing agricultural soil quality (Pahalvi *et al*., 2021). The use of organic fertilizers provides abundant nutrients and organic matter, thereby improving soil fertility and fertilizer efficiency (He *et al*., 2022). One alternative that can be used to improve soil fertility is the use of biochar.

Biochar is known for its ability to improve soil biological, chemical, and physical properties, and optimize fertilizer use (Diatta *et al*., 2020). The use of biochar is a good method to overcome the problem of acidic soils by increasing pH values, increasing cation exchange capacity (CEC), and providing nutrients such as N, P, and K (Andini *et al*., 2024). Biochar utilization is an effective method to reduce greenhouse gas emissions to the atmosphere and can affect climate change by reducing N_2O and CH_4 emissions from soil and sequestering carbon dioxide (Samoraj *et al*., 2022). Biochar is produced from biomass through thermal combustion in an oxygen-deficient environment and can be derived from various biomass sources. To produce biochar, various biomass sources are used, including wood pellets, which are derived from agricultural waste (Amalina *et al*., 2022; Kazimierski *et al*., 2022; Khedulkar *et al*., 2023; Rani *et al*., 2023). Biomass wastes that can be used for biochar production are oil palm OPEFB and rubber wood.

Indonesia is the world's largest palm oil producer, with oil palm plantations in 2023 reaching 15,435.70 ha (BPS, 2024). In Indonesia, crude palm oil (CPO) production reaches approximately 46.5 million tons per year (Santoso *et al*., 2025), with oil palm empty fruit bunches (OPEFB) constituting 22–23% of fresh fruit bunches (FFB), a proportion nearly equal to the CPO yield (Nabila et al., 2023). Consequently, the palm oil industry generates an estimated 46.5 million tons of OPEFB annually. Waste from the palm oil industry comes from several stages of the process, including plant cultivation, processing fresh fruit bunches in palm oil mills into CPO, as well as oil extraction from palm kernels to produce palm kernel oil (PKO) (Praevia & Widayat, 2022). OPEFB are solid wastes derived from the palm oil processing industry. OPEFB wastes that are not properly utilized produce a foul odor and a place for insect flies to nest, and are waste that can pollute the environment and spread disease seeds (Sopiah *et al*., 2017).

In Indonesia, rubber wood (*Hevea brasiliensis*) is a prospective forestry commodity and the second-largest producer of natural rubber in the world, after Thailand. Indonesia accounts for nearly 40% of the total rubber plantations worldwide (Bazenet *et al*., 2021; Ridjayanti *et al*., 2023). The total area of rubber plantations in Indonesia reached 3.68 million hectares, consisting of large plantations of 437.4 thousand ha (12.7%) and smallholder plantations of 3.25 million ha (88.3%) (BPS, 2020). Rubber wood is primarily cultivated for its latex, which is tapped to produce natural rubber, a key material for various industries such as automotive, footwear, and medical products (Yang *et al*., 2022). However, after years of tapping, the wood develops numerous latex channels and an irregular structure, making it less suitable for certain high-value applications. Consequently, a significant portion of harvested rubber wood is underutilized or discarded after rejuvenation (Vachlepi, 2019). To reduce waste and increase its value, this wood can be processed into biochar, a carbon-rich material that has potential applications in agriculture as a soil amendment.

The wastes in form of OPEFB and rubber wood requires further utilization to produce useful and valuable products, namely biochar pellets. Pelletization of biochar is one of the innovations to increase the efficiency of its use in growing media (Wang *et al*., 2022). Biochar pellets have a more stable structure, facilitate application, and allow a more controlled release of nutrients (Mohammadi, 2021). Previous research by Rafly *et al*. (2022) showed that applying OPEFB biochar increased sengon growth by 1.2 times better and faster.

Research by Wijaya *et al*. (2025) revealed that the use of OPEFB could increase the growth of *Falcataria moluccana* seedlings. Meanwhile, Dharmakeerthi *et al*. (2012) showed that the application of rubber wood biochar (up to 2% to the plant media) can increase the growth of rubber plants under nursery conditions tested in this experiment. Therefore, research on the effect of the addition of biochar from OPEFB and rubber wood waste on the growth of oil palm seedlings is important to determine their effectiveness in supporting plant growth in the nursery phase. This study aims to analyze the effect of adding biochar pellets derived from OPEFB and rubber wood waste on the growth of oil palm seedlings.

2. MATERIALS AND METHODS

2.1. Research Location and Materials

This research was conducted from September 2024 to February, 2025 in the Greenhouse and Silviculture and Forest Protection Laboratory, Faculty of Agriculture, University of Lampung. The equipment used in this study included polybags with a volume of 220 cm^3, calipers, analytical scales, ruler, tweezers, leaf color chart or leaf color scale, cutter, oven, measuring cup, magnifying glass, thermohygrometer, lux meter, laptop, camera and stationery. The materials used in this study were oil palm seedlings, OPEFB and rubber wood biochar pellets.

2.2. Preparation for Pelletizing

Biomass pellets were produced using waste from OPEFB and rubber wood. The process was started by cutting the material into small chips using a cutting tool. A hammer mill is then used to reduce the size of the wood chips and

OPEFB into powder. The sawdust is dried until the moisture content of the raw material reaches 8–12%, after which a pellet press is used to form the pellets. The final step is cooling the finished pellets.

2.3. Production of Biochar Pellet

Biochar was produced from OPEFB and rubber wood pellets using a double-drum pyrolysis system (Figure 1). The apparatus consisted of a small inner drum serving as the primary pyrolysis chamber and a larger outer drum functioning as the combustion chamber. The feedstocks (OPEFB and rubber wood pieces) were loaded into the inner drum, which was then sealed tightly to prevent air ingress and ensure an oxygen-limited environment during pyrolysis. The sealed inner drum was then placed inside the larger drum, and fuelwood was arranged between the two drums. Combustion was initiated from the top layer of the fuelwood to ensure a downward burning pattern. Once the flames were stable, the outer drum was closed securely to maintain heat retention and ensure continuous combustion. To achieve successful pyrolysis, it was essential that the fire remained stable and did not extinguish prior to sealing the outer drum. The pyrolysis process proceeded for approximately 8–12 hours. After completion, the system was allowed to cool naturally before the biochar pellets were removed from the inner drum.

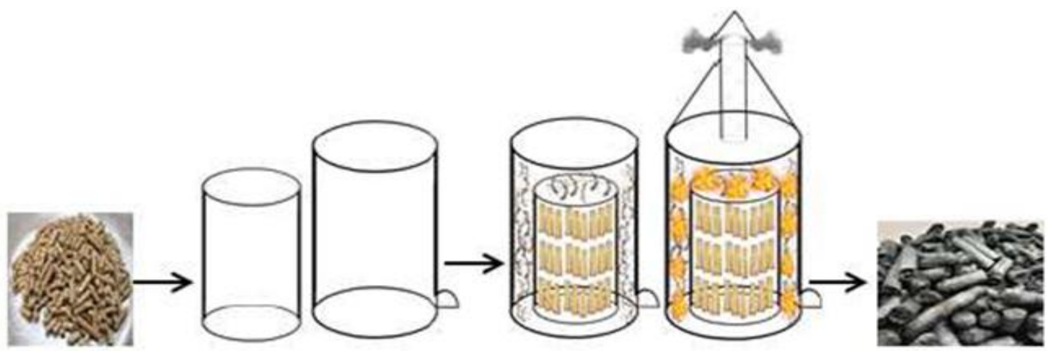

Figure 1. Schematic diagram of the pyrolysis process using a double-drum retort.

2.4. Preparation of Oil Palm Plants and Growing Media

The plants used in this study were oil palm plants of the same type and age. The plants are 7 months old and are of the *tenera* palm (oil palm from a cross between *dura* and *pisifera* oil palms).

The growing media used the top layer of soil (topsoil) taken from the Integrated Field Laboratory of the Faculty of Agriculture, University of Lampung. Before the soil was put into polybags, it was dried in the sun (for 2–3 days) to sterilize and to avoid mold. The growing media was put into polybags measuring 20 cm × 30 cm with the addition of biochar pellets in it. The biochar used is divided into 3 different doses of 0%, 5%, and 10%, which are mixed with the soil evenly, and then the mixture of soil and biochar pellets is put into polybags (Figure 2).

Figure 2. Mixing biochar and soil with doses of 0% biochar, 5% biochar, and 10% biochar used per polybag (w/w).

Seedling height was measured from the ground or from a standard 2 cm peg to the tip of the highest leaf using a ruler. The number of midribs counted is the midribs that have opened completely. The characteristics of a fully opened midrib are a minimum length of 5–10 cm and a minimum area of 3–5 cm. The circumference of the stem was measured using a tape measure about 1 cm from the ground by measuring two opposite sides; the values were summed and averaged. Plant growth measurements were taken at 4–12 weeks after planting, with a 2-week interval.

2.5. Root Dry Weight (g)

After separating the parts (stems and leaves) with the below part (roots), then weighing the wet weight of the plant is carried out by weighing the plant samples, then recording the results of weighing according to the sample and then putting it in an envelope according to the plant sample, the envelope wall is then perforated for the release of water freed from plant tissue. Weighing was done using digital scales. Measurements were taken at the end of the study.

2.6. Stem Dry Weight (g) and Leaf Dry Weight (g)

After the process of weighing the wet weight of the stem is carried out, the wet weight sample of the stem is put into the oven at a temperature of 80 °C for 48 hours. After that, it was put into an applicator for 30 minutes and weighed, then put back into the oven at 80 °C for 12 hours, then put back into the applicator for 30 minutes and weighed again. If the first and second weighings are not different, it means that the drying has been perfect; if the second weighing is smaller, it is necessary to repeat the drying for another 1 hour at 80 °C, so that the weighing becomes constant.

2.7. Design Experiments and Statistical Analysis

This research was arranged according to Factorial Randomized Group Design with 2 treatment factors and 10 replications. The first factor was source of biochar (K), comprised of two types including K1 (OPEFB biochar pellets) and K2 (rubber wood biochar pellets). The second factor was dose of biochar applications (T), consisted of 3 levels, namely T0 = Control (without treatment), T1 = 5% oil palm EFB biochar pellets/polybag (w/w); and T2 = 10% OPEFB biochar pellets/polybag (w/w). Observations and measurements of the additional height, diameter and number of leaves of oil palm plants were carried out once a week for 12 weeks.

The data were analyzed using analysis of variance (ANOVA) following the factorial Randomized Group Design procedure, followed by Duncan's Multiple Range test (DMRT) at 5% significant level.

3. RESULTS AND DISCUSSION

3.1. Results

Based on the results of the analysis of variance, the provision of OPEFB biochar pellets and rubber wood biochar pellets on the growth of oil palm plants (*Elaeis guineensis*) has a significant impact on the growth of height, diameter and number of leaves on oil palm plants. The results of the analysis of variance are presented in Table 1.

The DMRT test results of plant height growth are presented in Table 2. The table shows that the provision of OPEFB biochar pellets is more noticeable than the height growth using rubber wood pellets. The results of the DMRT on the dose of plant height growth are presented in Table 3. The table shows that the greater the dose, the more significant the height growth.

Table 1. The results of the ANOVA on the use of biochar pellets of oil palm EFB and rubber wood on the growth of oil palm seedlings

Observation Parameter	Factor B	Factor T	Factor B * Factor T
Plant height	*	*	ns
Number of fronds	ns	*	ns
Plant Diameter	ns	*	ns
Frond dry weight	ns	*	ns
Total dry weight	*	*	*
Root dry weight	ns	*	ns

Note: * = significant, tn = not significant

Table 2. Effect of biochar types on the height of oil palm seedlings

Treatments	Plant height (cm)
OPEFB biochar pellets	71.14b
Rubber wood biochar pellets	67.77a

Notes: Numbers followed by the same letter indicate no significant difference. Sig value = 0.924.

Table 3. The result of the DMRT on the effect of biochar dosage treatments on the height of oil palm seedlings

Biochar Doses	Seedling Height (cm)	Stem Diameter (cm)	Number of Fronds	Frond Dry Weight (g)	Total Dry Weight (g)
0%	63.71a	6.167a	9.389a	47.90a	56.339a
5%	67.31b	8.005b	12.556b	64.972b	87.456b
10%	69.93c	8.622b	13.611b	65.861b	87.917b
Sig value	0.924*	1.0*	1.0*	1.0*	0.932*

Notes: Numbers followed by the same letter indicate no significant difference based on the DMRT at 5% level. * = significant at α = 5% level.

The results of the DMRT on the diameter of the circumference of the oil palm stump are presented in Table 3. The table shows a very significant interaction effect in the treatment between doses of 0%, 5%, and 10%. While the interaction at a dose of 5% with 10% was not significant. The DMRT results of the number of fronds show that the greater the dose of biochar pellets applied, the greater the increase in the number of fronds on oil palm plants. The results of the DMRT for dry weight of palm fronds are presented in Table 3. In the table, there is a significant difference in the treatment of 0% OPEFB biochar pellet dose with 5% and 10%. At doses of 5% and 10%, the dry weight of fronds was not significantly different. The results of the DMRT for the total dry weight of oil palm plants show that the differences are significant at doses of 0%, 5%, and 10% (Table 8). While at a dose of 5% and 10% was not significant.

The results of the DMRT for the dry weight of oil palm plant roots are presented in Table 4. The table shows an interaction between dose types; it is significant at doses of 0%, 5%, and 10%. While between biochar pellets also showed a significant difference.

Table 4. Results of the DMRT on the effect of interaction (biochar types * dosage) on the root dry weight of oil palm seedlings

Treatments	Doses		
	0%	5%	10%
OPEFB biochar pellets	16.88a A	23.68b B	25.84c B
Rubber wood biochar pellets	17.54a A	19.51b A	20.04c A

Notes: Numbers followed by the same letter indicate no significant difference. Value sig = 1.0.

3.2. Discussion

This study demonstrated that adding biochar at doses of 5% and 10% can enhance the growth of oil palm compared to the control group (0%). The results for growth in biochar pellets derived from oil palm empty fruit bunches (OPEFB) showed significant improvements in various parameters: for height, the measurements were 11.7 cm for 0%, 18.9 cm for 5%, and 21.4 cm for 10%. In terms of diameter, the values were 1.8 cm for 0%, 2.8 cm for 5%, and 3.64 cm for 10%. Additionally, for the number of fronds, the counts were 4 for 0%, 6.7 for 5%, and 8 for 10%. For biochar pellets made from rubber wood, the height measurements were 12.74 cm for 0%, 12.94 cm for 5%, and 15.67 cm for 10%. The diameter of the stump circumference showed 1.4 cm for 0%, 3.34 cm for 5%, and 3.64 cm for 10%. The number of midribs counted 2.67 for 0%, 5.67 for 5%, and 6.67 for 10%. Research indicates that biochar application has a positive impact on plant growth, including oil palm. Marhani *et al.* (2022) reported that applying biochar derived from OPEFB increased the dry weight of oil palm plants by 80% compared to the control group. Yunedi & Perdana (2023) also noted that biochar can improve soil structure and support plant biomass growth, particularly in marginal soils. Furthermore, Hariyono (2021) found that using biochar from biomass waste significantly increased plant biomass through enhanced cation exchange capacity and soil water retention.

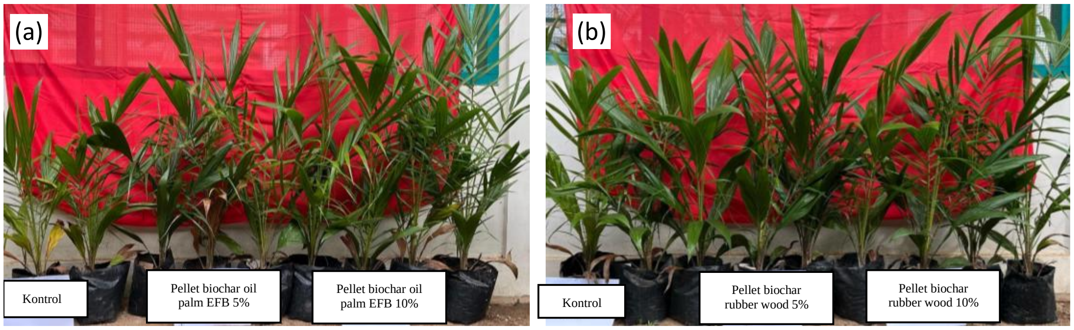

Figure 3. Height growth of oil palm plants to the application of biochar pellets: a) OPEFB, and b) rubber wood

Based on the research conducted, the dose of biochar has more influence on plant growth than the type of biochar used. Research also shows that different types of biochar do not always have a significant effect on plant growth when the biochar characteristics and the dose used are equivalent. Jeffery *et al*. (2017) stated that differences in biochar raw materials do not always have a significant impact on plant growth if biochar characteristics and application doses are equivalent. Bian *et al*. (2019) supported this by mentioning that even though biochar raw materials differ, their impact on plant growth does not always show significant differences in the short term. Febrina *et al*. (2024) also stated that various types of biochar have relatively similar long-term effects on plant growth on ultisol soil media. However, Tarigan & Nelvia (2021) showed that the application of PKS biochar had no significant effect on sweet corn plant height in ultisol soil, which has similar characteristics to oil palm growing media. Dharmakeerthi *et al*. (2012) supported this finding, showing that rubber wood biochar showed better characteristics in increasing plant growth than PKS biochar.

Biochar plays a role in improving soil quality through various mechanisms. Evizal & Prasmatiwi (2023) found that biochar from woody biomass significantly improved plant growth by increasing organic carbon content and soil moisture. Abujabhah *et al*. (2016) supported this finding, stating that wood biochar plays a role in improving soil porosity and significantly increases leaf growth. Agegnehu *et al*. (2016) also reported that biochar application significantly increased plant vegetative growth through improved soil quality. Liu *et al*. (2020) found that biochar increased plant physiological activity and stimulated more leaf growth.

4. CONCLUSION

Based on the results of the study, the utilization of biochar from OPEFB and rubber wood significantly affects oil palm seedling growth, especially on the parameters of plant height, number of leaves, stem diameter, and dry weight. Increasing the biochar dose to 10% resulted in a significant increase in growth parameters as compared to that of control (0%). OPEFB biochar at a dose of 10% was able to increase plant height up to 21.4 cm, stem diameter 3.64 cm, and number of leaves 8 strands, while rubber wood biochar at the same dose increased plant height up to 15.67 cm, diameter 3.64 cm, and number of leaves 6.67 strands. Although OPEFB biochar showed higher values for some parameters, statistically, both types of biochar were equally effective at the same dose. These results indicate that the biochar dose is more influential than the biochar type in increasing growth. Biochar plays a vital function in improving soil quality by increasing pH, organic matter content, cation exchange capacity, porosity, and water availability. Thus, the utilization of biochar from agricultural waste has the potential as an environmentally friendly technology to increase crop productivity, especially in low-fertility land, as well as a useful organic waste management solution. For future research, it is recommended to evaluate the long-term effects of OPEFB and rubber wood biochar on oil palm growth and yield under field conditions, as this study was limited to the seedling stage. It is also interesting to explore the combination of biochar with other sustainable soil amendments to enhance the effectiveness

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REFERENCES

Abujabhah, I.S., Bound, S.A., Doyle, R., & Bowman, J.P. (2016). Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. *Applied soil ecology*, ***98***, 243-253. https://doi.org/10.1016/j.apsoil.2015.10.021

Aji, A.C., Masykuri, M., & Rosariastuti, R. (2019). Fitoremediasi logam kromium di tanah sawah dengan rami (boehmeria nivea) dan environmental health agriculture system (EHAS). *Bioeksperimen: Jurnal Penelitian Biologi*, ***5***(2), 61-69. https://doi.org/10.23917/bioeksperimen.v5i2.9232

Amalina, F., Razak, A.S.A., Krishnan, S., Zularisam, A.W., & Nasrullah, M. (2022). A comprehensive assessment of the method for producing biochar, its characterization, stability, and potential applications in regenerative economic sustainability – A review. *Cleaner Materials*, ***3***, 100045. https://doi.org/10.1016/j.clema.2022.100045

Andini, A., Yulies, U.S., & Chandra, T.O. (2024). Pemberian biochar tankos dan kotoran sapi terhadap ketersediaan unsur hara N, P, K dan pertumbuhan tanaman terong (*Solanum molongena* L.) di tanah alluvial. *Jurnal Sains Pertanian Equator*, ***13***(3), 877. https://doi.org/10.26418/jspe.v13i3.75407

Agegnehu, G., Bass, A.M., Nelson, P.N., & Bird, M.I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, ***543***, 295-306. https://doi.org/10.1016/j.scitotenv.2015.11.054

Bazenet, R.A., Hidayat, W., Ridjayanti, S.M., Riniarti, M., Banuwa, I.S., Haryanto, A., & Hasanudin, U. (2021). Pengaruh kadar perekat terhadap karakteristik briket arang limbah kayu karet (*Hevea brasiliensis* Muell. Arg). *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, *10*(3), 283-295. https://doi.org/10.23960/jtep-l.v10i3.283-295

Bian, X., Ren, Z., Zeng, L., Zhao, F., Yao, Y., & Li, X. (2024). Effects of biochar on the compressibility of soil with high water content. Journal of Cleaner Production, ***434***, 140032. https://doi.org/10.1016/j.jclepro.2023.140032

BPS. (2020). *Statistik Indonesia 2020*. Badan Pusat Statistik.

BPS. (2024). *Statistik Kelapa Sawit Indonesia*. Badan Pusat Statistik.

Dewi, D.S., & Afrida, E. (2022). Kajian Respon penggunaan pupuk organik oleh petani guna mengurangi ketergantungan terhadap pupuk kimia. *All Fields of Science Journal Liaison Academia and Sosiety*, ***2***(4), 131–135. https://doi.org/10.58939/afosj-las.v2i4.458

Dharmakeerthi, R.S., Chandrasiri, J.A.S., & Edirimanne, V.U. (2012). Effect of rubber wood biochar on nutrition and growth of nursery plants of *Hevea brasiliensis* established in an Ultisol. *SpringerPlus*, ***1***(1), 84. https://doi.org/10.1186/2193-1801-1-84

Diatta, A.A., Fike, J.H., Battaglia, M.L., Galbraith, J.M., & Baig, M.B. (2020). Effects of biochar on soil fertility and crop productivity in arid regions: a review. *Arabian Journal of Geosciences*, ***13***(14), 595. https://doi.org/10.1007/s12517-020-05586-2

Emilia, I., Ardila, L., & Anggraini, P. (2024). Pemanfaatan limbah tandan kosong kelapa sawit menjadi pupuk kompos di Desa Suka Damai Kecamatan Tunggal Jaya Musi Banyuasin. *Environmental Science Journal (Esjo) : Jurnal Ilmu Lingkungan*, ***2***(2), 34–39. https://doi.org/10.31851/esjo.v2i2.15870

Evizal, R., & Prasmatiwi, F.E. (2023). Biochar: Pemanfaatan dan aplikasi praktis. *Jurnal Agrotropika*, ***22***(1), 1-12. https://doi.org/10.23960/ja.v22i1.7151

Febrina, W., Awaluddin, A., Saryono, S., & Helwani, Z. (2024). Karakterisasi biochar dari tandan kosong kelapa sawit. *Jurnal Unitek*, ***17***(2), 293-301. https://doi.org/10.52072/unitek.v17i2.1150

Hariyono, B. (2021). Multifungsi biochar dalam budi daya tebu. *Buletin Tanaman Tembakau, Serat dan Minyak Industri, **13***(2), 94-112.

He, H., Peng, M., Lu, W., Hou, Z., & Li, J. (2022). Commercial organic fertilizer substitution increases wheat yield by improving soil quality. *Science of The Total Environment*, ***851***, 158132. https://doi.org/10.1016/j.scitotenv.2022.158132

Jeffery, S., Abalos, D., Spokas, K.A., & Verheijen, F.G. (2015). *Biochar effects on crop yield*. In: Biochar for environmental management (pp. 301-325). Routledge. London. https://doi.org/10.4324/9780203762264

Kazimierski, P., Januszewicz, K., Godlewski, W., Fijuk, A., Suchocki, T., Chaja, P., Barczak, B., & Kardaś, D. (2022). The course and the effects of agricultural biomass pyrolysis in the production of high-calorific biochar. *Materials*, ***15***(3), 1038. https://doi.org/10.3390/ma15031038

Khedulkar, A.P., Pandit, B., Dang, V.D., & Doong, R. (2023). Agricultural waste to real worth biochar as a sustainable material for supercapacitor. *Science of The Total Environment*, ***869***, 161441. https://doi.org/10.1016/j.scitotenv.2023.161441

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G., & Paz-Ferreiro, J. (2013). Biochar's effect on crop productivity and the dependence on experimental conditions—a meta-analysis of literature data. *Plant and soil*, ***373***, 583-594. DOI: https://doi.org/10.1007/s11104-013-1806-x

Marhani, M., Musa, Y., Sahur, A., & Laban, S. (2023). Analisis interaksi biochar tandan kosong kelapa sawit (TKKS) dan bakteri metanotrof terhadap peningkatan produksi padi sawah di Kabupaten Morowali. A*groland: Jurnal Ilmu-ilmu Pertanian, 30*(3), 287-298. https://doi.org/10.22487/agrolandnasional.v30i3.1823

Mohammadi, A. (2021). Overview of the benefits and challenges associated with pelletizing biochar. *Processes*, ***9***(9), 1591. https://doi.org/10.3390/pr9091591

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***, 113193. https://doi.org/10.1016/j.rser.2023.113193

Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A.N. (2021). Chemical fertilizers and their impact on soil health. In *Microbiota and Biofertilizers, Vol 2.* Springer International Publishing: 1–20. https://doi.org/10.1007/978-3-030-61010-4_1

Praevia, M.F., & Widayat, W. (2022). Analisis Pemanfaatan limbah tandan kosong kelapa sawit sebagai cofiring pada PLTU Batubara. *Jurnal Energi Baru dan Terbarukan*, ***3***(1), 28-37. https://doi.org/10.14710/jebt.2022.13367

Rafly, N.M., Riniarti, M., Hidayat, W., Prasetia, H., Wijaya, B.A., Niswati, A., & Banuwa, I.S. (2022). Pengaruh pemberian biochar tandan kosong kelapa sawit terhadap pertumbuhan sengon (*Falcataria moluccana*). *Journal of Tropical Upland Resources*, ***4***(1), 1–10.

Rani, I.T., Yoo, J., Park, B.B., Hidayat, W., Wijaya, B.A., Lee, S., Kim, S., Choi, H., Chun, D., Im, H., & Kim, S. (2023). Wood pellet driven-biochar characterization produced at different targeted pyrolysis temperatures. *Jurnal Sylva Lestari*, ***11***(3), 558–571. https://doi.org/10.23960/jsl.v11i3.796

Ridjayanti, S.M., Bazenet, R.A., Banuwa, I.S., Riniarti, M., & Hidayat, W. (2023). Karakteristik arang kayu karet (*Hevea brasiliensis*) yang diproduksi menggunakan dua tipe tungku pirolisis. *Jurnal Belantara*, ***6***(1). https://doi.org/10.29303/jbl.v6i1.815

Santoso, A.D., Sribudiani, E., Priyanti, A., Yulistiani, D., Daulay, H., Hanifa, R., Mahendri, I.G.A.P., Priyono, Yaumidin, U.K., Ali, A., Erwan, E., Iskandar, D., & Djarot, I.N. (2025). Sustainable utilization of palm oil industry by-products for livestock feed: A digestibility and environmental assessment. *Case Studies in Chemical and Environmental Engineering*, ***12***, 101263. https://doi.org/10.1016/j.cscee.2025.101263

Samoraj, M., Mironiuk, M., Witek-Krowiak, A., Izydorczyk, G., Skrzypczak, D., Mikula, K., Baśladyńska, S., Moustakas, K., & Chojnacka, K. (2022). Biochar in environmental friendly fertilizers - Prospects of development products and technologies. *Chemosphere*, ***296***, 133975. https://doi.org/10.1016/j.chemosphere.2022.133975

Sopiah, N., Prasetyo, D., & Aviantara, D.B. (2017). Pemanfaatan Potensi tandan kosong kelapa sawit (*Elais guineensis*) sebagai adsorben kadmium terlarut. *Jurnal Riset Teknologi Pencegahan Pencemaran Industri*, ***8***(2), 55–66. https://doi.org/10.21771/jrtppi.2017.v8.no2.p55-66

Tarigan, A.D., & Nelvia, N. (2020). Pengaruh Pemberian biochar tandan kosong kelapa sawit dan mikoriza terhadap pertumbuhan dan hasil tanaman jagung manis (*Zea mays sacharrat*a L.) di tanah ultisol. *Jurnal Agroekoteknologi*, ***12***(1), 23-37. http://dx.doi.org/10.33512/jur.agroekotetek.v12i1.8769

Vachlepi, A. (2019). Prospek pemanfaatan kayu karet sebagai bahan baku pembuatan pulp. *Warta Perkaretan*, ***1***(1), 47–60. https://doi.org/10.22302/ppk.wp.v1i1.593

Wang, C., Luo, D., Zhang, X., Huang, R., Cao, Y., Liu, G., Zhang, Y., & Wang, H. (2022). Biochar-based slow-release of fertilizers for sustainable agriculture: A mini review. *Environmental Science and Ecotechnology*, ***10***, 100167. https://doi.org/10.1016/j.ese.2022.100167

Wijaya, B.A., Riniarti, M., Hidayat, W., Prasetia, H., Yoo, J., & Park, B.B. (2025). Field Evaluation of biochar application on the early growth of *Falcataria moluccan*a: Effects of pyrolysis temperatures and biochar application rates. *Jurnal Sylva Lestari*, ***13***(1), 248-263. https://doi.org/10.23960/jsl.v13i1.1134

Yang, H., Sun, Z., Liu, J., Zhang, Z., & Zhang, X. (2022). The development of rubber tapping machines in intelligent agriculture: A Review. *Applied Sciences*, ***12***(18), 9304. https://doi.org/10.3390/app12189304

Yunedi, S., & Perdana, A. (2023). Pemberian fungi mikoriza arbuskula dan biochar terhadap pertumbuhan dan hasil tanaman kedelai (*Glycine max* (L.) Merril) pada tanah ultisol. *Jurnal Agroteknologi, **14***(1), 33-42. http://dx.doi.org/10.24014/ja.v14i1.16725