

Effect of Tapioca Binder Concentration on the Quality of Charcoal Briquettes Produced from Oil Palm Trunk and Laban Wood

Hisyammudin ^{1✉}, Zakwan ², Heri Purwanto ³

(1,2,3) Plantation Product Processing Technology Study Program, Institut Teknologi Sawit Indonesia, Medan, Indonesia

Abstract: This study examined the effect of tapioca binder concentration on the quality of charcoal briquettes produced from oil palm trunk and laban wood. A non-factorial Completely Randomized Design was applied using five binder concentrations: V1 (10%), V2 (15%), V3 (20%), V4 (22.5%), and V5 (25%), with three replications. Moisture content, ash content, and calorific value were evaluated. One-way analysis of variance showed a highly significant treatment effect for every parameter ($p < 0.001$), and Duncan's Multiple Range Test at the 5% level separated all treatment means. Increasing binder concentration raised moisture content from 4.131% to 6.175% and ash content from 3.263% to 4.900%, while calorific value decreased from 7,185.33 to 6,325.98 cal/g. All treatments met SNI 01-6235-2000. The best treatment was V1, consisting of 47.5% oil palm trunk charcoal, 47.5% laban wood charcoal, and 10% tapioca binder. The results demonstrate that controlling binder concentration is essential for balancing particle cohesion and thermal quality.

Article history:

Received: 21 June 2026

Revised: 24 July 2026

Accepted: 26 July 2026

Published: 28 July 2026

Keyword:

charcoal briquette, oil palm trunk, laban wood, tapioca binder, calorific value

This is an open-access article under the [CC-BY-SA License](#).



How to cite: Hisyammudin, H., Zakwan, Z., & Purwanto, H. (2026). Effect of Tapioca Binder Concentration on the Quality of Charcoal Briquettes Produced from Oil Palm Trunk and Laban Wood. RESWARA: Jurnal Riset Ilmu Teknik, 4(3), 727-735. <https://doi.org/10.70716/reswara.v4i3.644>

INTRODUCTION

The increasing demand for renewable and environmentally friendly energy sources has encouraged the development of biomass-based fuels as alternatives to fossil energy. Indonesia, as one of the world's largest oil palm-producing countries, generates abundant lignocellulosic residues from plantation and processing activities. These residues include oil palm trunks, fronds, shells, and empty fruit bunches, which can be converted into value-added energy products rather than being left to decay or openly burned.

Charcoal briquettes are solid fuels produced by compacting carbonized biomass particles with a binder. Compared with loose biomass, briquettes generally provide higher energy density, more uniform dimensions, easier handling and storage, and more stable combustion. Briquetting therefore supports both renewable-energy production and residue management. Oil palm trunk is particularly relevant because large quantities become available during replanting, whereas laban wood (*Vitex pubescens*) has a dense, carbon-rich structure and a relatively high heating potential. Alimah (2020) described laban as a useful woody resource, and Kahariyadi et al. (2015) showed that oil palm trunk charcoal and laban wood charcoal can be combined to produce briquettes with acceptable moisture, ash, and calorific characteristics.

Binder concentration is a critical formulation variable because the binder must generate sufficient interparticle adhesion while preserving the combustible fraction of the briquette. Tapioca starch is widely used because it is inexpensive, readily available, and develops adhesive properties

after gelatinization. Nevertheless, excessive binder can increase water retention and mineral residue while replacing part of the carbonized biomass, thereby affecting moisture content, ash content, and calorific value. Moisture influences ignition and combustion efficiency, ash represents non-combustible residue, and calorific value indicates the heat released per unit mass.

Recent literature confirms that starch is among the most frequently applied organic binders in biomass densification, but its concentration must be optimized because mechanical cohesion and fuel quality do not always improve simultaneously (Obi et al., 2022). Amin et al. (2017), Anizar et al. (2020), Vegetama (2022), Veronika (2024), and Yudi et al. (2025) reported that binder proportion can alter moisture content, ash formation, and heating value. Studies of blended biomass also indicate that the interaction between feedstock composition and binder proportion determines the compactness, combustible fraction, and thermal behavior of the final product (Waheed et al., 2023).

The novelty of this study lies in isolating the effect of tapioca binder concentration in a specific mixed-charcoal system. Kahariyadi et al. (2015) primarily varied the relative proportion of oil palm trunk charcoal and laban wood charcoal. In contrast, the present study maintained an equal contribution of the two charcoal sources within the biomass fraction and varied the tapioca binder from 10% to 25%. This design makes it possible to identify whether changes in moisture content, ash content, and calorific value are attributable to binder concentration rather than to a changing ratio between the two charcoal feedstocks.

Accordingly, this study aimed to evaluate the effect of tapioca binder concentration on the quality of charcoal briquettes produced from oil palm trunk and laban wood, determine the statistical differences among treatments, and identify the formulation that provides the most favorable combination of low moisture, low ash, and high calorific value.

RESEARCH METHOD

Research Design

This study employed a non-factorial Completely Randomized Design (CRD) with five levels of tapioca binder concentration and three replications per treatment. The two charcoal materials contributed equal proportions within the charcoal fraction of each formulation. The treatments were as follows:

- V1 = 47.5% oil palm trunk charcoal + 47.5% laban wood charcoal + 10% tapioca binder
- V2 = 45.0% oil palm trunk charcoal + 45.0% laban wood charcoal + 15% tapioca binder
- V3 = 40.0% oil palm trunk charcoal + 40.0% laban wood charcoal + 20% tapioca binder
- V4 = 38.75% oil palm trunk charcoal + 38.75% laban wood charcoal + 22.5% tapioca binder
- V5 = 37.5% oil palm trunk charcoal + 37.5% laban wood charcoal + 25% tapioca binder

Briquette Preparation

Oil palm trunk and laban wood were carbonized separately and allowed to cool before being reduced to charcoal powder. The powders were sieved to obtain a uniform fraction and then weighed according to the treatment formulations. Tapioca flour was dispersed in water and heated until a gelatinized adhesive was formed. The adhesive was mixed thoroughly with the two charcoal powders until a homogeneous mixture was obtained. Each mixture was compacted in a briquette mold, removed carefully from the mold, and dried until a stable mass was reached before laboratory testing. The same

preparation sequence was applied to all treatments so that tapioca concentration was the only experimental factor.

Quality Testing

Moisture content was determined gravimetrically by weighing the briquette sample before and after oven drying to a constant mass. Moisture content was calculated as the percentage mass loss relative to the initial sample mass: moisture content (%) = $[(\text{initial mass} - \text{dry mass}) / \text{initial mass}] \times 100$.

Ash content was determined by combusting a known mass of dried sample in a furnace until a constant mineral residue was obtained. Ash content was calculated as: ash content (%) = $(\text{mass of ash} / \text{initial dry sample mass}) \times 100$.

Calorific value was measured using bomb calorimetry. A known mass of briquette was combusted in a closed oxygen atmosphere, and the released heat was converted to energy per unit sample mass and reported in cal/g. The measured moisture content, ash content, and calorific value were then compared with the requirements of SNI 01-6235-2000.

Data Analysis

For each parameter, the statistical model was $Y_{ij} = \mu + \tau_i + \epsilon_{ij}$, where Y_{ij} is the observation from treatment i and replication j , μ is the overall mean, τ_i is the treatment effect, and ϵ_{ij} is the random error. A one-way analysis of variance (ANOVA) was used to test the effect of tapioca binder concentration. When the ANOVA was significant, Duncan's Multiple Range Test (DMRT) at the 5% level was used to separate treatment means. Results are presented as individual replications, mean $\pm$ standard deviation, and DMRT letter groups. Means followed by different letters are significantly different at $p < 0.05$.

RESULTS AND DISCUSSION

Statistical Significance of the Treatments

The ANOVA results confirmed that tapioca binder concentration had a highly significant effect on moisture content, ash content, and calorific value. For all three parameters, the probability value was below 0.001. The subsequent DMRT separated all five treatment means, demonstrating that the monotonic changes across binder concentrations were systematic treatment responses rather than random variation among replications.

Table 1. Summary of one-way ANOVA for briquette quality parameters

Parameter	df treatment	df error	F-value	p-value
Moisture content	4	10	532.834	< 0.001
Ash content	4	10	1,935.755	< 0.001
Calorific value	4	10	1,359.115	< 0.001

Moisture Content

Moisture content is an important briquette-quality parameter because water must be evaporated before sustained combustion can occur. The mean moisture content increased progressively from 4.131% in V1 to 6.175% in V5. ANOVA indicated a highly significant treatment effect, and DMRT showed that every binder concentration produced a distinct mean. Therefore, even the intermediate increases in tapioca concentration generated measurable changes in moisture retention.

The increase is associated with the hydrophilic nature of starch. During gelatinization, the starch structure develops a network containing numerous hydroxyl groups that can interact with water. A greater binder proportion consequently introduces more water-retaining sites and can slow moisture removal during drying. Similar trends have been reported for tapioca- and starch-bound briquettes (Maryono et al., 2013; Suharto et al., 2016; Amin et al., 2017; Anizar et al., 2020). Saeed et al. (2021) likewise demonstrated that moisture condition influences the physical and thermal behavior of densified biomass.

From a fuel-performance perspective, lower moisture is advantageous because less combustion energy is consumed in water evaporation. All treatments remained below the SNI maximum of 8%; however, V1 was the most favorable treatment because it minimized moisture while still containing sufficient binder for briquette formation. This result is consistent with Yudi et al. (2025), who reported that lower tapioca concentration generally produced lower-moisture briquettes.

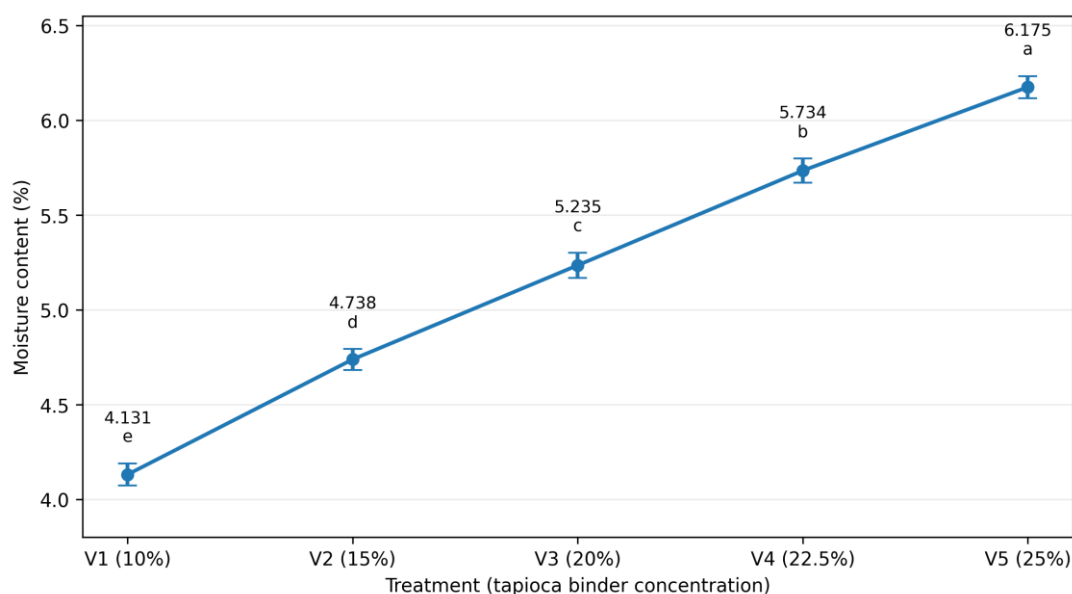


Figure 1. Mean moisture content of briquettes at different tapioca binder concentrations. Error bars represent standard deviation; different letters indicate significant differences according to DMRT ($p < 0.05$).

Table 2. Moisture content of charcoal briquettes at different tapioca binder concentrations

Treatment	R1	R2	R3	Mean $\pm$ SD (%)	DMRT
V1	4.196	4.088	4.109	4.131 $\pm$ 0.057	e
V2	4.802	4.701	4.712	4.738 $\pm$ 0.055	d
V3	5.207	5.311	5.187	5.235 $\pm$ 0.067	c
V4	5.692	5.808	5.703	5.734 $\pm$ 0.064	b
V5	6.108	6.207	6.210	6.175 $\pm$ 0.058	a

Note: Means followed by different letters differ significantly according to DMRT at $p < 0.05$.

Ash Content

Ash content represents the non-combustible mineral residue remaining after complete burning. The mean ash content increased from 3.263% in V1 to 4.900% in V5. The ANOVA was highly

significant, and DMRT assigned a different letter to every treatment, indicating that the increases were statistically distinct across the entire 10–25% binder range.

The increase can be interpreted as a combined dilution and residue effect. As the proportion of tapioca binder increased, the relative proportion of carbonized oil palm trunk and laban wood decreased. At the same time, inorganic constituents associated with the binder and the briquette mixture remained as residue after combustion. The result agrees with Maryono et al. (2013), Anizar et al. (2020), Harlina et al. (2021), and Setyawan and Ulfa (2019), who observed that binder type or concentration can alter the amount of ash produced by biomass briquettes.

Low ash is preferred because it increases the proportion of combustible matter, reduces residue-handling requirements, and lowers the risk of deposits in combustion equipment. Although all treatments satisfied the SNI maximum of 8%, V1 was superior because it produced approximately one-third less ash than V5. This difference is practically meaningful for repeated household or small-industrial use, where residue accumulation affects cleaning frequency and combustion continuity.

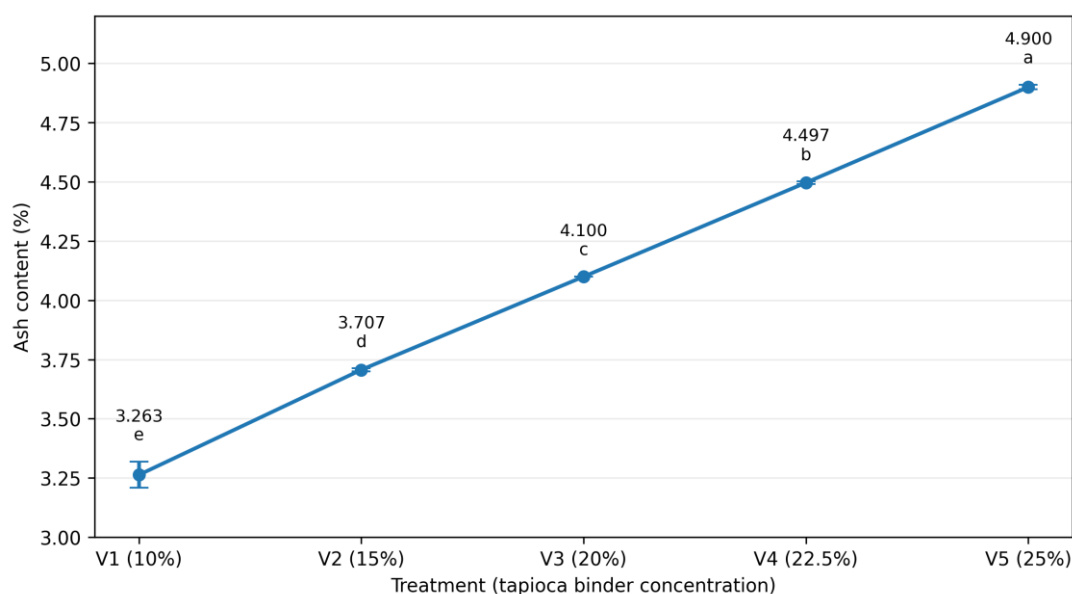


Figure 2. Mean ash content of briquettes at different tapioca binder concentrations. Error bars represent standard deviation; different letters indicate significant differences according to DMRT ($p < 0.05$).

Table 3. Ash content of charcoal briquettes at different tapioca binder concentrations

Treatment	R1	R2	R3	Mean $\pm$ SD (%)	DMRT
V1	3.20	3.29	3.30	3.263 $\pm$ 0.055	e
V2	3.71	3.71	3.70	3.707 $\pm$ 0.006	d
V3	4.10	4.10	4.10	4.100 $\pm$ 0.000	c
V4	4.49	4.50	4.50	4.497 $\pm$ 0.006	b
V5	4.90	4.91	4.89	4.900 $\pm$ 0.010	a

Note: Means followed by different letters differ significantly according to DMRT at $p < 0.05$.

Calorific Value

Calorific value indicates the amount of thermal energy released during combustion and is a primary measure of fuel quality. In contrast to moisture and ash, calorific value declined as binder

concentration increased. V1 produced the highest mean value of 7,185.33 cal/g, whereas V5 produced 6,325.98 cal/g. ANOVA and DMRT confirmed significant differences among all five treatments.

The decline can be explained by three related mechanisms. First, higher moisture requires part of the released heat to evaporate water before useful heat becomes available. Second, higher ash represents a larger non-combustible fraction. Third, increasing the binder from 10% to 25% displaced carbonized oil palm trunk and laban wood, thereby reducing the proportion of high-energy carbonaceous material in each unit mass of briquette. The combined effect of these mechanisms produced a steady reduction of approximately 12% from V1 to V5.

This relationship is consistent with Saleh (2013), Aziz et al. (2019), Nugraha et al. (2017), Vegatama (2022), Veronika (2024), and Yudi et al. (2025). Obi et al. (2022) emphasized that binder selection and concentration influence both mechanical and energetic quality, while Owino et al. (2024) showed that the thermal performance of composite briquettes depends on the balance among carbonized feedstock, binder, moisture, and residual ash. Under the conditions of the present study, the 10% binder level best preserved the energy-rich charcoal fraction.

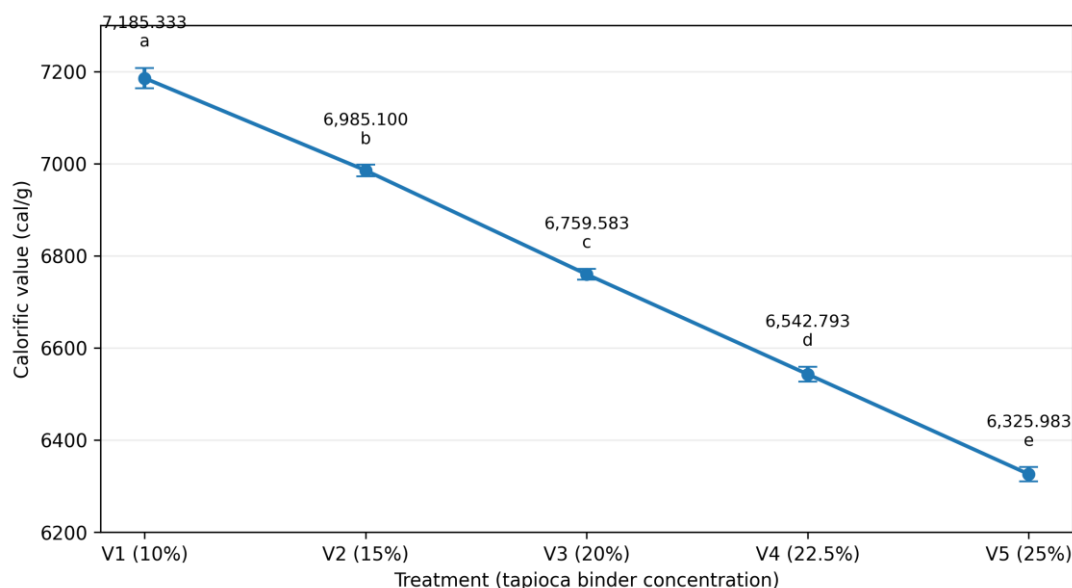


Figure 3. Mean calorific value of briquettes at different tapioca binder concentrations. Error bars represent standard deviation; different letters indicate significant differences according to DMRT ($p < 0.05$).

Table 4. Calorific value of charcoal briquettes at different tapioca binder concentrations

Treatment	R1	R2	R3	Mean $\pm$ SD (cal/g)	DMRT
V1	7,185.10	7,163.13	7,207.77	7,185.33 $\pm$ 22.32	a
V2	6,992.91	6,970.88	6,991.51	6,985.10 $\pm$ 12.33	b
V3	6,752.45	6,773.18	6,753.12	6,759.58 $\pm$ 11.78	c
V4	6,532.79	6,561.49	6,534.10	6,542.79 $\pm$ 16.21	d
V5	6,317.73	6,343.75	6,316.47	6,325.98 $\pm$ 15.40	e

Note: Means followed by different letters differ significantly according to DMRT at $p < 0.05$.

Overall Briquette Quality and Practical Implications

The three quality parameters showed a consistent formulation response: increasing tapioca binder from 10% to 25% increased moisture and ash while decreasing calorific value. All formulations met SNI 01-6235-2000, but compliance alone did not mean that the treatments were equivalent. Statistical separation demonstrated that V1 consistently provided the lowest moisture, the lowest ash, and the highest calorific value. The result reinforces the principle that binder concentration should be optimized rather than maximized (Obi et al., 2022).

The findings also clarify the contribution of the specific feedstock system. Oil palm trunk provides a productive route for utilizing replanting residue, while laban wood contributes a carbon-rich woody fraction. Maintaining a 1:1 ratio between the two charcoals and limiting tapioca to 10% preserved the combustible fraction without eliminating the adhesive function. Similar studies of mixed lignocellulosic feedstocks have shown that well-balanced blends can improve particle contact and support useful fuel characteristics (Kahariyadi et al., 2015; Waheed et al., 2023).

For small-scale briquette producers, the V1 formulation has two practical advantages. It uses less tapioca than the other treatments, which can reduce binder consumption and production cost, and it produces less ash while delivering more heat per unit mass. The formulation can therefore support the conversion of oil palm replanting residue into an alternative solid fuel for household heating, small agro-industries, and other controlled thermal applications.

The recommendation is limited to the quality attributes measured in this study. A higher binder concentration may improve compressive strength, shatter resistance, or handling durability even when it reduces calorific value. Future work should therefore combine proximate and calorific analysis with density, compressive strength, drop resistance, ignition time, burning rate, emissions, storage stability, and production-cost analysis before full commercial scale-up.

Table 5. Summary of briquette quality and compliance with SNI 01-6235-2000

Treatment / standard	Moisture content (%)	Ash content (%)	Calorific value (cal/g)	SNI compliance
V1	4.131	3.263	7,185.33	Meets
V2	4.738	3.707	6,985.10	Meets
V3	5.235	4.100	6,759.58	Meets
V4	5.734	4.497	6,542.79	Meets
V5	6.175	4.900	6,325.98	Meets
SNI 01-6235-2000	Maximum 8	Maximum 8	Minimum 5,000	—

CONCLUSION

Tapioca binder concentration significantly affected the moisture content, ash content, and calorific value of charcoal briquettes produced from oil palm trunk and laban wood ($p < 0.001$). DMRT showed that all treatment means differed significantly. Increasing the binder concentration from 10% to 25% increased moisture content from 4.131% to 6.175% and ash content from 3.263% to 4.900%, while decreasing calorific value from 7,185.33 to 6,325.98 cal/g. Although all treatments complied with SNI 01-6235-2000, V1—47.5% oil palm trunk charcoal, 47.5% laban wood charcoal, and 10% tapioca binder—provided the best combination of low moisture, low ash, and high calorific value. The 10% binder formulation is therefore recommended for the measured quality criteria and offers a practical opportunity to reduce binder use, lower residue generation, and convert oil palm replanting

waste into a higher-value renewable solid fuel. Pilot-scale validation should additionally assess mechanical durability, combustion behavior, emissions, and economic feasibility.

REFERENCES

- Alimah, D. (2020). Karakteristik dan budidaya laban (*Vitex pubescens*) untuk tujuan kayu. *Jurnal Hutan Tropis*, 5(April), 74–79.
- Amin, A. Z., Pramono, & Sunyoto. (2017). Pengaruh variasi jumlah perekat tepung tapioka terhadap karakteristik briket arang tempurung kelapa. *Saintekno: Jurnal Sains dan Teknologi*, 15(2). <https://doi.org/10.15294/saintekno.v15i2.11693>
- Anizar, H., Sribudiani, E., & Somadona, S. (2020). Pengaruh bahan perekat tapioka dan sagu terhadap kualitas briket arang kulit buah nipah. *Perennial*, 16(1), 11–17. <https://doi.org/10.24259/perennial.v16i1.9159>
- Aziz, M. R., Siregar, A. L., Rantawi, A. B., & Rahardja, I. B. (2019). Pengaruh jenis perekat pada briket cangkang kelapa sawit terhadap waktu bakar. *Prosiding Seminar Nasional Sains dan Teknologi*, 1–10.
- Demirbaş, A. (2004). Briquetting properties of biomass waste materials. *Energy Sources*, 26(1), 83–91. <https://doi.org/10.1080/00908310490248174>
- Harlina, A. C., Ropiudin, & Ritonga, A. M. (2021). Pengaruh kadar perekat molase dan lama pengeringan terhadap proses pembuatan biobriket dari tempurung kelapa dan sekam padi. *Journal of Agricultural and Biosystem Engineering Research*, 2(2), 19–27. <https://doi.org/10.20884/1.jaber.2021.2.2.4984>
- Kahariyadi, A., Setyawati, D., Nurhaida, Diba, F., & Roslinda, E. (2015). Kualitas arang briket berdasarkan persentase arang batang kelapa sawit (*Elaeis guineensis* Jacq.) dan arang kayu laban (*Vitex pubescens* Vahl). *Jurnal Hutan Lestari*, 3(4), 561–568.
- Maryono, Sudding, & Rahmawati. (2013). Pembuatan dan analisis mutu briket arang tempurung kelapa ditinjau dari kadar kanji. *Jurnal Chemica*, 14(1), 74–83.
- Nugraha, A., Widodo, A., Wahyudi, S., & Suprpto, W. (2017). Pengaruh komposisi bahan terhadap karakteristik pembakaran briket. *Jurnal Rekayasa Mesin*, 8(1), 29–36.
- Obi, O. F., Pecenka, R., & Clifford, M. J. (2022). A review of biomass briquette binders and quality parameters. *Energies*, 15(7), 2426. <https://doi.org/10.3390/en15072426>
- Owino, C. A., Lubwama, M., Yiga, V. A., Were, F., Bongomin, O., & Serugunda, J. (2024). Mechanical and thermal properties of composite carbonized briquettes developed from cassava (*Manihot esculenta*) rhizomes and groundnut (*Arachis hypogea* L.) stalks with jackfruit (*Artocarpus heterophyllus*) waste as binder. *Discover Applied Sciences*, 6, 428. <https://doi.org/10.1007/s42452-024-06123-6>
- Saeed, A. A. H., Yub Harun, N., Bilad, M. R., Afzal, M. T., Parvez, A. M., Roslan, F. A. S., Abdul Rahim, S., Vinayagam, V. D., & Afolabi, H. K. (2021). Moisture content impact on properties of briquette produced from rice husk waste. *Sustainability*, 13(6), 3069. <https://doi.org/10.3390/su13063069>
- Saleh, A. (2013). Efisiensi konsentrasi perekat tepung tapioka terhadap nilai kalor pembakaran pada biobriket batang jagung (*Zea mays* L.). *Jurnal Teknik Kimia*, 19(2), 78–89.
- Sarwono, E. (2018). Pengaruh variasi komposisi batang, pelepah, dan daun tanaman kelapa sawit terhadap kualitas briket bioarang. *Jurnal Energi dan Lingkungan*, 14(2), 11–22.
- Setyawan, B., & Ulfa, R. (2019). Analisis mutu briket arang dari limbah biomassa campuran kulit kopi dan tempurung kelapa dengan perekat tepung tapioka. *Edubiotik: Jurnal Pendidikan, Biologi dan Terapan*, 4(2), 110–120. <https://doi.org/10.33503/ebio.v4i02.259>
- Suharto, B., Sutanahaji, A. T., & Sunarsih. (2016). Uji kualitas briket kotoran sapi pada variasi kadar perekat tapioka dan suhu pengeringan. *Jurnal Sumberdaya Alam dan Lingkungan*, 3(2), 39–44.

-
- Vegatama, M. R. (2022). Variasi komposisi biobriket arang terhadap karakteristik termal. *Jurnal Ilmiah Ecosystem*, 22(2). <https://doi.org/10.35965/eco.v22i2.1505>
- Veronika, N. (2024). Pengaruh persentase perekat terhadap pembuatan biobriket dari pelepah sawit dan tempurung kelapa. *Jurnal Sains dan Ilmu Terapan*, 7(1), 82–97. <https://doi.org/10.59061/jsit.v7i1.974>
- Waheed, M. A., Akogun, O. A., & Enweremadu, C. C. (2023). Influence of feedstock mixtures on the fuel characteristics of blended cornhusk, cassava peels, and sawdust briquettes. *Biomass Conversion and Biorefinery*, 13, 16211–16226. <https://doi.org/10.1007/s13399-023-04039-6>
- Yudi, A., Sari, F. P., & Rahman, A. (2025). Pengaruh konsentrasi perekat tepung tapioka terhadap mutu biobriket pelepah pinang (*Areca catechu* L.). *SAINTI: Majalah Ilmiah Teknologi Industri*, 22(1), 1–11.