BORNEO'S PALM BIOMASS: TRANSFORMING WASTE INTO "BLACK GOLD"

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Endowed with the tropical rainforest climate, Malaysia is rich in biomass resources, and Sarawak, in particular, produces the highest amount of palm biomass in the country. Across Malaysia, large quantities of Palmae biomass are generated annually from agriculture, including oil palm, sago, and coconut. It is crucial to explore these under-utilized palm biomass residues which can be transformed into value-added products that support sustainability.

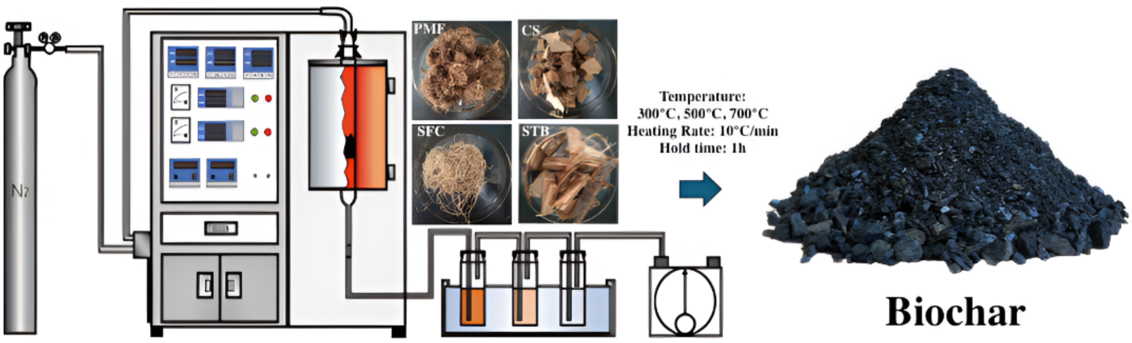
Malaysia's biomass landscape is dominated by palm-oil residues, over half of the national total, spanning 6.49 million t of palm kernel shells (PKS), 260,800 t of empty fruit bunches (EFB), and 159,900 t of palm mesocarp fibre (PMF) (Su et al. 2022). Coconut milk production generates coconut husk fibre and shell, while sago starch extraction leaves behind streams after streams of coarse and fine sago fibre, trunk bark, and pith. When these resource streams leak from the proper management loop, such as being used for open burning or abandoned in the field, of which their unmanaged decay would release pollutants and breed pests and diseases, hence forfeiting their latent value. Circular bio-economy strategies seek to plug these leaks. Technologies such as pyrolysis convert surplus biomass into biochar, a carbon-rich material that returns nutrients to the soil, boosts crop yields, and locks carbon into long-lived pools. By designing similar "closed-loop" pathways for each residue stream, Malaysia can transform agricultural by-products from disposal liabilities into circular assets that power rural livelihoods and climate resilience.

Pyrolysis, a process of heating biomass under low oxygen, can transform palm wastes into value-added biochar, bio-oil and syngas fuels. This approach kills three birds with one stone: (1) reduces waste, (2) creates useful products, and (3) locks away the carbon. Biochar is increasingly being recognized as an ideal material for sustainable land management (Bandh 2022; Dwibedi et al. 2022). When added to the soil, it can improve its fertility, retain the moisture, while sequester carbon into stable form. Biochar made from well-studied feedstocks such as coconut shells reliably raises soil pH, enriches nutrient availability, and stimulates plant growth. Malaysia's under-explored residues, including palm mesocarp fibre (PMF), sago trunk bark (STB), and coarse sago fibre (SFC), may deliver equal or even greater agronomic benefits, yet remain to be rigorously evaluated. Our recent study of four under-utilized Bornean residues, PMF, STB, SFC and coconut shell (CS) can shed light into the potential. The resulting biochars were profiled for pyrolysis yield, surface chemistry, fixed-carbon content and sequestration potential. Finally, we field-tested each biochar in a paddy pot trial, generating the comparative data set that links local biomass streams to tangible soil benefits for Malaysian rice growers.

Why Palmae Waste Is a Circular Goldmine?

Four major palm residues were investigated in this study:

- Palm-Mesocarp Fibre (PMF) that is the leftover pulp from oil extraction, carries the highest ash load among our four feedstocks (≈ 12 wt %)—meaning it is laced with farm-friendly minerals such as K, Ca and Mg (Yeong et al. 2025). Nitrogen sits at a respectable 2.6 wt.%, giving its future biochar a nutritional head-start. Moisture is high, so pyrolysis must be tuned, but the payoff is a nutrient-rich char that can close the loop on palm-oil plantations.
- Dense, woody, and almost mineral-free, Coconut Shell (CS) carries just ~ 0.5 wt.% ash and negligible nitrogen (Yeong et al. 2025). What it lacks in nutrients it more than makes up for in fixed carbon and lignin, yielding a biochar celebrated for ultra-high porosity and long-term stability in soil. Think of CS as the "carbon backbone" of any biochar blend—ideal for locking up CO_2 and polishing polluted soils, even if it offers little direct fertiliser value. → Loops durable carbon back into plantation soils while supporting remediation markets.
- Sago Coarse Fibre (SFC) is a by-product of sago-starch milling, SFC is rich in reactive cellulose and hemicellulose, driving easy devolatilization yet leaving just ≈ 3 wt.% ash and ≤ 0.5 wt.% N (Yeong et al. 2025). The result: a clean, low-ash char that can lighten compacted paddy soils and serve as a carrier for compost or microbial inoculants. Although nutrient-poor on its own, SFC biochar's high surface area makes it a natural sponge for fertiliser retention (e.g. cutting nutrient runoff) while closing the sago loop in Sarawak.
- Sago Trunk Bark (STB) being woodier than SFC, clocks in at ≈ 22 wt.% fixed carbon and just ≈ 2 wt.% ash (Yeong et al. 2025), blending the stability of lignin with a modest mineral profile. Its balanced chemistry produces a mid-range biochar, i.e. stabler than SFC, more nutritive than CS, that can both sequester carbon and supply trace minerals to rice paddies. By valorising trunk bark otherwise discarded after felling, STB biochar keeps the sago value chain circular from plantation to pot.



Picture 1: The process from crop waste to "black gold".

Striking the Right Balance in the Pyrolysis Condition

Batches of each residue were slow-pyrolyzed at 300 °C, 500 °C and 700 °C. Char yields fell as the furnace got hotter, i.e. roughly 40 wt.% remained at 300 °C, dropping to about 20 wt.% at 700 °C. Every sample emerged strongly alkaline (pH 9–10), potentially a tonic for typical acid-washed tropical soils. The "sweet spot" proved to be 500 °C with a gentle 10 °C min^{-1} ramp: hot enough to build fixed-carbon, stability and porosity, yet cool enough to preserve the mineral ash that plants crave.

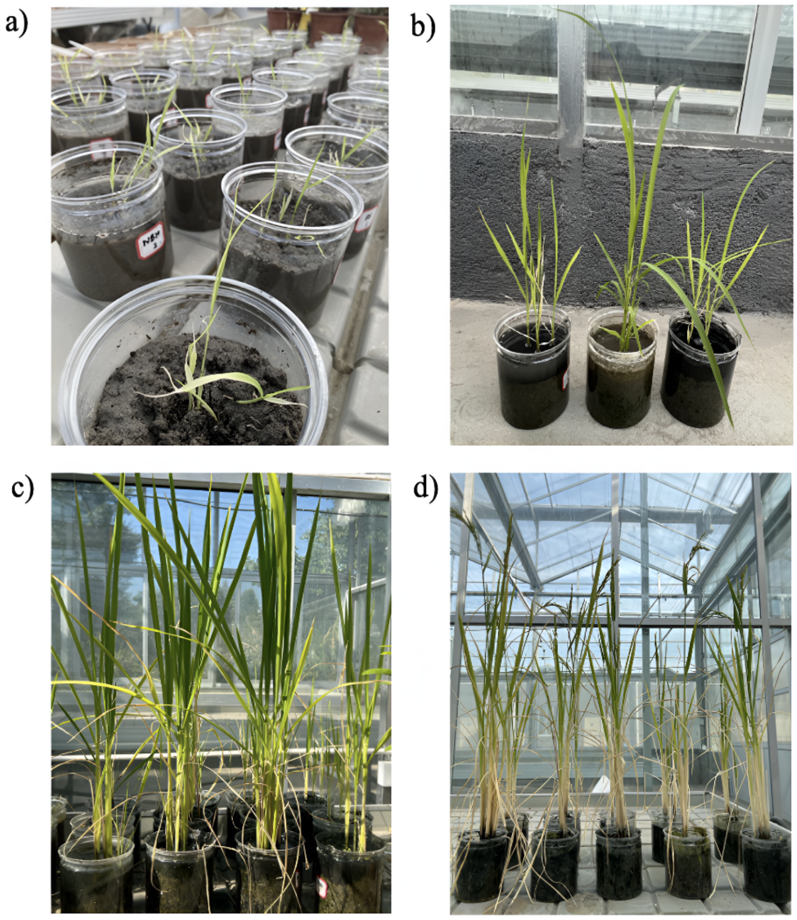
Among the 500 °C chars, PMF500 stole the show with surface area (~13 $m^2\ g^{-1}$). The surface area is modest compared with SFC500 and CS500 (150–190 $m^2\ g^{-1}$), yet its richer nutrient ash and robust cation-exchange capacity (~25 cmol kg^{-1}) make it the better all-round soil conditioner. CS500, by contrast, is almost pure carbon (C/N ≈ 630) and virtually nutrient-free; ideal for uptake of heavy-metal or hydrocarbon pollution rather than feeding crops. STB500 lagged on surface area and therefore on nutrient-holding power, limiting its appeal for either fertilization or remediation.

For the thermogravimetric (TG) and derivative thermogravimetric (DTG), kinetic fits using the Coats–Redfern method reinforce the story: PMF posts the lowest activation energy (≈ 61 kJ mol^{-1}), followed by CS (≈ 67 kJ mol^{-1}) and the more variable SFC (80–139 kJ mol^{-1}). In plain terms, PMF is likely the more cost-effective biomass to carbonise, good news for Sarawak's palm-oil mills that have mountain load of mesocarp fibre. The full TG/DTG traces and kinetic analysis could be referred to our recent publication (Yeong et al. 2025).

Soil Gains and the Carbon Ledger

In greenhouse pot trials on acid paddy soil (Picture 2), palm mesocarp fibre (PMF) biochar produced at 500 °C (PMF500) emerged as the all-round performer. When incorporated at 10 wt.% alongside standard fertilizer, PMF500 lifted (1) soil pH and cation-exchange capacity (CEC), (2) plant height, tiller number, and 1 000-grain weight, ultimately translating into the highest rice yield of the series. The 5 wt.% rate also improved growth, but to a lesser extent.

Biochar's climate dividend was quantified with the recalcitrance index R_{50}, which benchmarks oxidation resistance against pure graphite. PMF500 returned $R_{50} = 0.53$, implying that ≈ 51 % of its carbon will persist in soil for centuries. Converting Malaysia's annual PMF stream at this setting could sequester ≈ 5.4 Mt CO_2 $year^{-1}$; even a 10 % uptake locks away ~0.43 Mt CO_2.



Picture 2: Growth stages of paddy rice in pot trial: a) seedling stage, b) tillering and vegetative growth, c) reproductive growth and grain formation, and d) maturation and harvesting.

From a conservative uptake scenario, i.e. carbonizing just 10 % of Malaysia's mesocarp-fibre stream, would sequester roughly 0.43 Mt CO_2 each year. Even this modest diversion delivers a regionally significant climate benefit, while the resulting biochar simultaneously enhances soil chemistry and structure. Such twin gains (carbon locked below-ground, productivity lifted above) sit at the heart of emerging "carbon-farming" initiatives.

Waste to Wealth for Sarawak's Future

What was once seen as "agricultural waste" – palm fibers, sago bark, sago fibers, coconut shells – is now proving to be a resource for sustainability. Slow-pyrolyzing these Bornean palmae residues into biochar delivers a three-way return: (1) it diverts biomass from open burning or landfill, (2) enriches the acidic tropical soils that constrain yields, and (3) immobilizes a sizeable share of carbon that would otherwise re-enter the atmosphere. Mesocarp fibre produces a nutrient-laden, moderately recalcitrant biochar that lifted rice growth in pot trials by improving pH, cation-exchange capacity and water retention. Sago residues, long a disposal headache for the starch industry, can be carbonized into a lightweight soil conditioner that loosens texture and curbs moisture loss, while coconut shell, already prized for high-grade char, excels as a stable carbon store and contaminant sorbent.

Widespread adoption of such biochar could weave climate-smart agriculture into existing plantation and paddy systems, boosting crop productivity even as long-lived carbon stocks accumulate in the soil—directly supporting Malaysia's emissions-reduction commitments. This approach exemplifies the *"waste-to-wealth"* concept – turning low-value biomass refuse into a product that supports both economic agriculture and environmental well-being. Institute of Urban Environment of the Chinese Academy of Sciences, Swinburne University of Technology Sarawak Campus and NGOs such as Alliance of Bioeconomy Community Development based in Sabah, all support the idea of managing palm wastes in such way that would feed the soil and temper climate change in one single stroke. "Borneo's black gold" (biochar) can potentially move from experimental plots to everyday farm practice across the region, enriching the soil for generations to come.

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