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CHARACTERISTICS OF CHARCOAL FROM *THYRSOSTACHYS SIAMENSIS*, *DENDROCALAMUS SERICEUS*, AND *GIGANTOCHLOA ALBOCILIATA* PRODUCED IN A HORIZONTAL KILN

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Bamboo processing often generates nodes as residues, which are typically underutilised despite their potential for bioenergy applications. This study aimed to evaluate the characteristics of charcoal produced from bamboo nodes using a 200 L horizontal kiln, with a focus on its efficiency and contribution to sustainable biomass utilisation. The research analysed charcoal yield, wood vinegar yield, fuel consumption, gross calorific value (GCV), net calorific value (NCV), and the proximate and elemental composition of three bamboo species: *Thyrsostachys siamensis*, *Dendrocalamus sericeus*, and *Gigantochloa albociliata*. Results revealed that *G. albociliata* nodes produced the highest charcoal yield (23.12 ± 2.65%) and wood vinegar yield (13.83 ± 1.91 kg), although with greater fuel consumption (16.83 ± 1.52 kg). Its charcoal also exhibited superior fuel properties, including the highest density (634.17 ± 8.73 kg m^{-3}), GCV (31.10 ± 0.15 MJ kg^{-1}), NCV (28.60 ± 0.14 MJ kg^{-1}), carbon content (82.26 ± 1.95%), and fixed carbon (78.95 ± 1.45%). These findings suggest that bamboo nodes, particularly from *G. albociliata*, can be effectively converted into high-quality charcoal using a horizontal kiln, offering a promising approach for valorising bamboo residues in renewable energy production.

Keywords: *Dendrocalamus sericeus*, *Gigantochloa albociliata*, gross calorific value, net calorific values, *Thyrsostachys siamensis*

INTRODUCTION

Bamboo (Bambusoideae) is a natural resource with high potential in both economic and environmental dimensions (Isukuru et al. 2023, Manandhar et al. 2019, Yadav & Mathur 2021) due to its rapid growth rate, resilience to diverse environmental conditions, and versatility for use across various sectors (Aryal & Kavitha 2023, Long et al. 2023, Maurya et al. 2024, Singh et al. 2016, Zhan et al. 2025)—from household-level applications to large-scale industrial production (Binfield et al. 2024, Borowski 2019, Pavate et al. 2024, Wahab et al. 2023, Wang et al. 2021). Thailand is recognised as one of the countries with high bamboo diversity, with approximately 60–90 species classified in over 13 genera distributed across different regions (Arthan et al. 2023, Bels et al. 2021, Sudchalaew et al 2021, Sungkaew et al. 2021). The physical characteristics of bamboo vary depending on growing conditions (Bhonde et al. 2014, Patel et al. 2023, Wanishdilokratn & Wanishdilokratn 2024). In particular, *Thyrsostachys siamensis*, *Dendrocalamus sericeus*, and *Gigantochloa albociliata* are prominent species valued for their mechanical strength and density, making them highly suitable for construction materials, furniture, handicrafts, and development into bio-based products aligned with the principles of the circular economy (Kasdi et al. 2023, Sae-Long et al. 2024, Tang et al. 2012, Tangphadungrat et al. 2023).

Despite its high utilisation potential, bamboo processing especially in small- and medium-sized enterprises and community-based industries produces a large volume of unused residues, particularly bamboo nodes (Gupta & Kumar 2008, Phimmachanh et al. 2015). These segments, which are usually removed during the production of chopsticks, skewers, or toothpicks, are often discarded due to their hardness and irregular shape (Hernisawati et al. 2025, Jodnok et al. 2021, Susanto et al. 2022, Wijitkosum 2023, Wijitkosum et al. 2024). In major bamboo processing areas such as Long District in Phrae Province, Thailand, bamboo

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node residues accumulate in substantial quantities without systematic management. Currently, resource recovery mechanisms for such biomass waste remain limited, highlighting the need for more sustainable and efficient waste utilisation approaches (Aizuddin et al. 2024, Kurniawan et al. 2023). Although several studies have examined bamboo charcoal production and species-level comparisons (Kumar & Chandrashekar 2014; Rusch et al. 2020; Jalil et al. 2022), few have specifically addressed the underutilised bamboo node residues or systematically evaluated their density-related influence on charcoal yield and pore characteristics. Moreover, while previous research has demonstrated the potential of bamboo-derived charcoal for activated carbon and adsorption applications (Mahanim et al. 2011; Divya et al. 2025), these insights have rarely been connected to residue valorisation strategies in small-scale or community-based contexts. Thus, there remains a gap in integrating species-specific evaluation, density-related properties, and practical kiln-based conversion of bamboo nodes, particularly in localised production systems.

To address this issue, the present study focuses on developing a horizontal 200-liter pyrolysis kiln for the conversion of bamboo nodes from *T. siamensis*, *D. sericeus*, and *G. albociliata* into high-quality biochar and wood vinegar. The production process was carried out at a target temperature of 300 °C, and evaluated in terms of charcoal yield, fuel consumption, and product characteristics. This research aims to provide an alternative approach to biomass waste management by transforming underutilised bamboo residues into value-added products. The results are expected to contribute to sustainable resource use, support local circular economy practices, and enhance community-level income generation in line with the Sustainable Development Goals (SDGs).

MATERIAL AND METHODS

The horizontal kiln preparation

The horizontal charcoal kiln was constructed from a 200 L oil drum. Heat from the fuel at the front was directly utilised to carbonise the raw materials. The construction process involved placing the 200 L drum horizontally and drilling a hole at its back. An L-shaped steel pipe, 10.16 cm (4-inches) in diameter and 75 cm in length, was welded to this hole to serve as the chimney opening. A bamboo pipe, 200 cm in length, was connected to the chimney, and a hole was drilled at the 100-cm mark along its length for collecting wood vinegar using a plastic cup. A 20 × 40 cm hole was drilled on the top of the stove to serve as a lid for inserting burning materials. In addition, a 15 × 15 cm hole was drilled on the lower front part of the stove for inserting fuel. Galvanised sheets were then attached to wooden posts to enclose the stove, and the surrounding area was filled with sand to retain heat. Finally, three concrete blocks were arranged to form a structure with a designated space for fuel insertion (Figure 1).

Figure 1 The horizontal kiln

Preparation of fuel and raw materials

The leftover eucalyptus wood was cut into pieces approximately 30 cm in length to be used as fuel. These pieces were then sun-dried until their moisture content reached about 30%, and the cumulative weight of the fuel was recorded. Three types of bamboo for raw materials—*T. siamensis*, *D. sericeus*, and *G. albociliata*—were sun-dried to control their moisture content. The moisture of the bamboo nodes was then measured using a moisture meter until it reached approximately 20%. Subsequently, 50 kg of each bamboo type were weighed for charcoal production in a kiln. For each type, three random bamboo nodes were selected for the charring process to calculate their density value as per the Equation (1).

$$\text{Density (kg m}^{-3}) = \frac{M}{V} \times 10^4 \quad (1)$$

where M = weight before treatment (g) and V = volume of sample (cm^3)

Bamboo node charcoal production process

Three replications of each of the three types of bamboo nodes were pyrolysed. The process began by uniformly arranging 50 kg of bamboo nodes into each charcoal kiln. The kilns were then sealed. The fuel was weighed every time additional fuel was added. Fire was ignited in the fuel at the front of the kiln, and the temperature was measured at 10-minute intervals. During hours 1–4, the heat was gradually increased. When the temperature reached approximately 80 °C, tubing and glass collection vessels were connected to collect wood vinegar. Heating was continued until an average temperature of 300 °C was achieved. From hours 5–9, the temperature was maintained at 300 °C. Subsequently, during hours 10–16, the fuel supply was gradually reduced in preparation for shutting down the kiln. Once the kiln had cooled, the weight of the charcoal produced was measured for data collection, and the kiln was cleaned. The quantity of charcoal yield was then calculated using Equation (2).

$$\text{Charcoal yield}(\%) = \frac{Wb - Wa}{Wa} \times 100 \quad (2)$$

where Wa = weight after treatment (kg) and Wb = weight before treatment (kg)

The wood vinegar was conditioned at room temperature for 45 days until sedimentation occurs. The liquid was then filtered, leaving only the purified wood vinegar.

Characterisation of charcoal properties

The charcoal obtained from the three bamboo species was conditioned at room temperature for 24 h prior to analysis. The gross calorific value (GCV) and net calorific value (NCV) were determined using a bomb calorimeter (Parr 6400, Parr Instrument Company, USA) following ASTM D5865-19a, with ground and pelletised samples. Volatile matter, ash content, and fixed carbon were analysed using a thermogravimetric analyser (TGA/DSC1, Mettler Toledo, Switzerland) under a nitrogen atmosphere with a heating program from 30–800 °C, according to ASTM D7582-15. Carbon and hydrogen contents were determined using a CHN analyser (Elementar Vario MACRO cube, Germany) in accordance with ASTM D5373-16.

Data analysis

Statistical differences in the gross calorific value, net calorific value, carbon, fixed carbon, volatile matter, ash content, and hydrogen content among treatments were analysed using one-way analysis of variance (ANOVA), followed by Duncan's New Multiple Range Test using SPSS for Windows (version 20.0).

RESULTS AND DISCUSSION

Moisture content and density

The moisture content (MC) of the three bamboo node types averaged 20.67 ± 1.39%. The highest density was found in *G. albociliata* (716.51 ± 7.06 kg m^{-3}), followed by *D. sericeus* (629.12 ± 9.71 kg m^{-3}) and *T. siamensis* (556.90 ± 9.43 kg m^{-3}), as shown in Table 1. The carbonisation process of different bamboo node types exhibited variations in average temperature, with an average duration of approximately 16 h, as illustrated in Figure 2. The result was similar to Huang et al. (2015) who showed that the bulk density of the Moso bamboo (*Phyllostachys edulis*) ranged from 601.00–640.00 kg m-^{3}. Moisture content is a critical parameter that must be appropriately controlled for effective utilisation (Ribeiro et al. 2019).

Table 1 Moisture content and density of three bamboo node types

Bamboo type	MC (%)	D (kg m^{-3})
Thyrsostachys siamensis	20.91 ± 1.42	556.90 ± 9.43
Dendrocalamus sericeus	20.87 ± 1.69	629.12 ± 9.71
Gigantochloa albociliata	20.24 ± 1.07	716.51 ± 7.06
Average	20.67 ± 1.39	634.17 ± 8.73

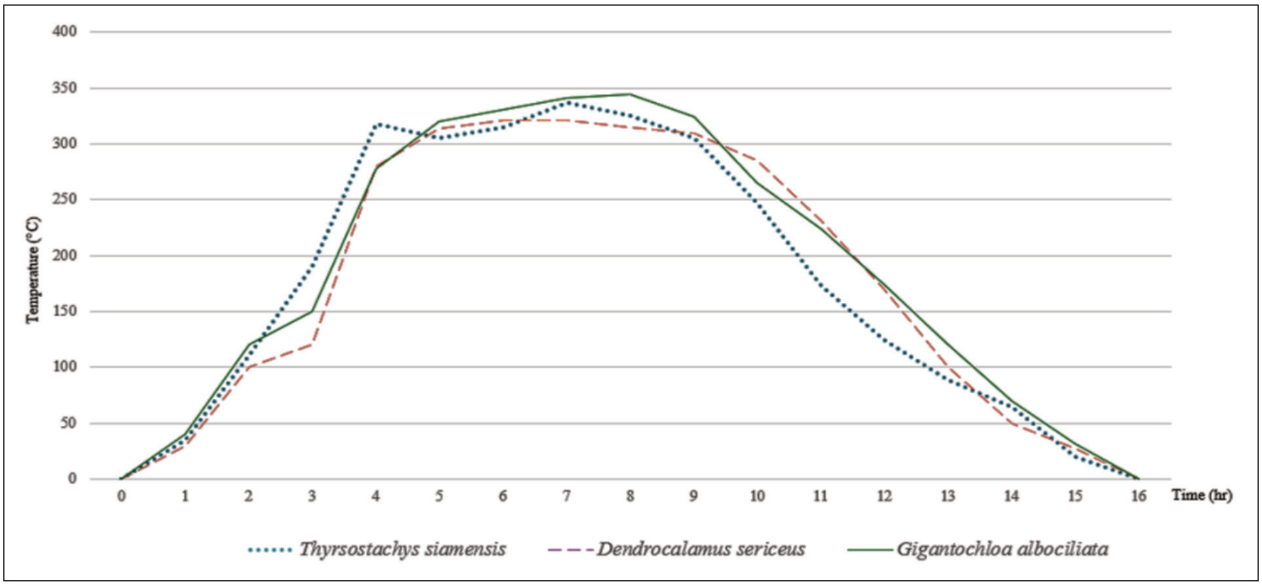

Figure 2 Charcoal burning temperatures of three bamboo node types at different time intervals

Fuel quantity, charcoal yield, and wood vinegar

The lowest fuel quantity was found in *T. siamensis* (16.44 ± 0.70 kg), followed by *D. sericeus* (16.55 ± 1.26 kg) and *G. albociliata* (16.83 ± 1.52 kg). The highest charcoal yield was observed in *G. albociliata* (23.12 ± 2.65%), followed by *D. sericeus* (20.42 ± 3.24%) and *T. siamensis* (19.61 ± 3.05%). This trend is consistent with the wood vinegar yield, which was 13.83 ± 1.91 kg, 13.53 ± 1.22 kg, and 12.47 ± 2.09 kg, respectively, as shown in Table 2.

The results, similar to those reported by Suryandari and Keyon (2023), indicated that charcoal yields from Apus bamboo, Javanese bamboo, Ori bamboo, and Yellow bamboo ranged between 19.67% and 33.16%. Conversely, the wood vinegar yield was approximately 10.00%. These percentages are influenced by the type of kiln used (Naruethanan et al. 2024, Sunphorka & Yangsawang 2023) and the type of wood being processed (Ouattara et al. 2023).

Charcoal composition

The highest gross calorific value was observed in *G. albociliata* node charcoal (31.10 ± 0.15 MJ kg^{-1}). This value was not significantly different ($p < 0.05$) from *D. sericeus* (30.92 ± 0.09 MJ kg^{-1}) but was significantly different from *T. siamensis* (30.82 ± 0.10 MJ kg^{-1}). These results align with the net calorific values of the bamboo species, which were 28.60 ± 0.14 MJ kg^{-1}, 28.42 ± 0.07 MJ kg^{-1}, and 28.36 ± 0.09 MJ kg^{-1}, respectively. There was no significant difference in carbon content among *G. albociliata* (82.26 ± 1.95%), *D. sericeus* (80.56 ± 1.53%), and *T. siamensis* (80.31 ± 1.67%). Similarly, the fixed carbon content showed no significant differences, measuring 78.95 ± 1.45%, 76.80 ± 1.62%, and 76.46 ± 1.35%, respectively. *Dendrocalamus sericeus* exhibited the

Table 2 Fuel quantity, charcoal yield, and wood vinegar of three bamboo node types

Bamboo type	Fuel quantity (kg)	Charcoal yield (%)	Wood vinegar (kg)
Thyrsostachys siamensis	16.44 ± 0.70	19.61 ± 3.05	12.47 ± 2.09
Dendrocalamus sericeus	16.55 ± 1.26	20.42 ± 3.24	13.53 ± 1.22
Gigantochloa albociliata	16.83 ± 1.52	23.12 ± 2.65	13.83 ± 1.91
Average	16.61 ± 1.16	21.05 ± 2.98	13.28 ± 1.74

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lowest volatile matter (9.38 ± 1.13%), which was not significantly different ($p < 0.05$) from *T. siamensis* (13.95 ± 1.59%) or *G. albociliata* (24.28 ± 1.09%). Finally, the ash content (4.38 ± 0.68% for *G. albociliata*, 6.58 ± 1.42% for *D. sericeus*, and 6.61 ± 1.59% for *T. siamensis*) and hydrogen content (2.18 ± 1.15%, 2.28 ± 1.17% and 4.27 ± 1.03%, respectively) also showed no significant differences among the species, as presented in Table 3. Based on the analysis of the three bamboo species, namely *T. siamensis, D. sericeus*, and *G. albociliata*, it was found that their properties are quite similar. However, *G. albociliata* tends to have a slightly higher fixed carbon (FC%) and carbon (C%) contents than the others, indicating a potential for longer-lasting heat release. Conversely, *D. sericeus* has the lowest volatile matter (VM%) content, which may make it slightly more difficult to ignite. Meanwhile, *T. siamensis* is distinguished by its lowest ash content (Ash%), meaning it has the least amount of residue after combustion. In conclusion, this chart is a useful tool for analysing and comparing the potential of each bamboo species as a biomass fuel, which can lead to selecting the most suitable species for specific utilisation purposes, as shown in Figure 3.

Table 3 Gross calorific value (GCV), net calorific value (NCV), carbon content (C), fixed carbon (FC), volatile matter (VM), ash and hydrogen (H) contents of three bamboo node types

Bamboo type	GCV ($MJ\ kg^{-1}$)	NCV ($MJ\ kg^{-1}$)	C (%)	FC (%)	VM (%)	Ash (%)	H (%)
T. siamensis	30.82 ± 0.10^{b}	28.36 ± 0.09^{b}	80.31 ± 1.67	76.46 ± 1.35	13.95 ± 1.59^{b}	6.61 ± 1.59	2.28 ± 1.17
D. sericeus	30.92 ± 0.09^{ab}	28.42 ± 0.07^{ab}	80.56 ± 1.53	76.80 ± 1.62	9.38 ± 1.13^{a}	6.58 ± 1.42	2.18 ± 1.15
G. albociliata	31.10 ± 0.15^{a}	28.60 ± 0.14^{a}	82.26 ± 1.95	78.95 ± 1.45	24.28 ± 1.09^{c}	4.38 ± 0.68	4.27 ± 1.03
Average	30.95 ± 0.11	28.46 ± 0.10	81.04 ± 1.72^{ns}	77.40 ± 1.47^{ns}	15.87 ± 1.27	5.86 ± 1.23^{ns}	2.91 ± 1.12^{ns}
p-value	0.006	0.006	0.383	0.160	< 0.001	0.128	0.106

ns = no significant difference; average values ± standard deviation

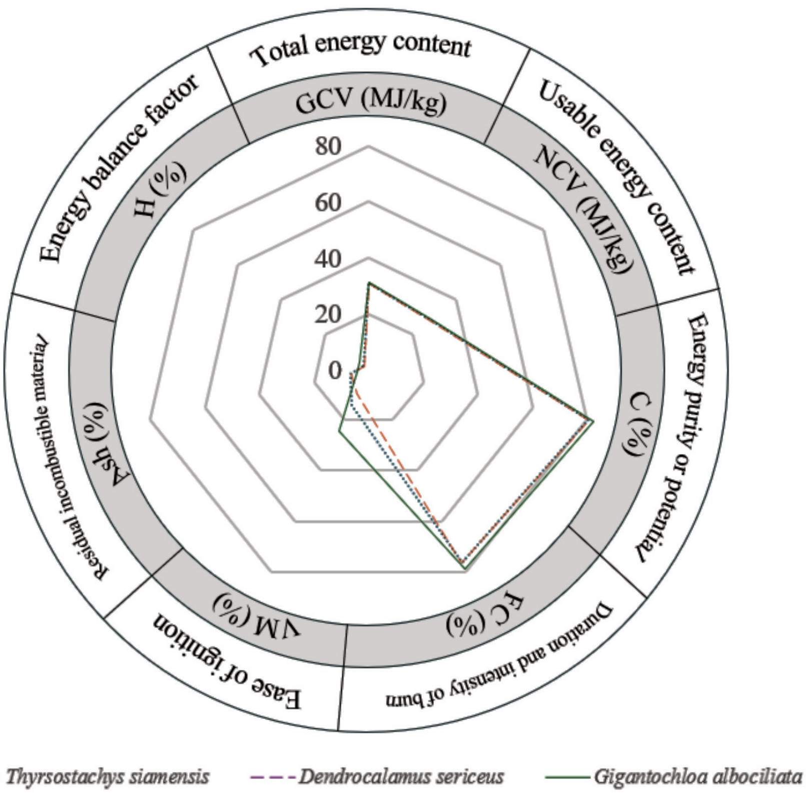

Figure 3 Composition and properties of the three types of bamboo node charcoal

The results are consistent with those reported by Kumar & Chandrashekar (2014), who found that the fixed carbon content, ash content, and calorific value of bamboo charcoal ranged from 75–81%, 5–10%, and 28–31 MJ kg^{-1}, respectively. Similarly, other studies on bamboo species such as *Bambusa vulgaris*, *Dendrocalamus asper*, and *Dendrocalamus giganteus* reported an average gross calorific value (GCV) of 29.28 MJ kg^{-1} (6,994 kcal kg^{-1}) (Rusch et al. 2020). Furthermore, Jalil et al. (2022) reported that the volatile matter content of *Gigantochloa levis* bamboo charcoal ranged from 14.00% to 18.00%. The chemical composition of bamboo charcoal is influenced not only by the bamboo species but also by several processing and material-related factors, including wood density, pyrolysis temperature, and the carbonisation method employed (Divya et al. 2025, Mahanim et al. 2011). Among these factors, wood density has been shown to play a particularly significant role, as it directly affects both the yield of charcoal and its calorific value (Crawford et al. 2023). Higher-density bamboo typically produces greater amounts of charcoal with enhanced energy content, while lower-density bamboo tends to yield less charcoal with reduced calorific potential. This highlights the importance of selecting appropriate bamboo species and optimising carbonisation conditions to maximise both charcoal production and energy efficiency.

CONCLUSION

Charcoal produced from *G. albociliata* nodes at 300 °C using a horizontal kiln yielded the highest outputs, with 23.12 ± 2.65% charcoal and 13.83 ± 1.91 kg wood vinegar, though it required substantial fuel consumption (16.83 ± 1.52 kg). The charcoal exhibited the highest density (634.17 ± 8.73 kg m^{-3}), which influenced its properties, including a gross calorific value of 31.10 ± 0.15 MJ kg^{-1}, carbon content of 82.26 ± 1.95%, and low ash content (4.38 ± 0.68%). These results indicate that bamboo node density significantly affects charcoal and wood vinegar yield, supporting their potential for utilisation.

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