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ORIGINAL ARTICLE

Physico-chemical and Energy Characteristic of Charcoal Derived from Two (Different) Sarawak Wild Bamboo Species

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ABSTRACT – Bamboo has a very rapid growth rate and has been considered a promising non-wood biomass material that has the potential as a feedstock for charcoal production. This study was carried out to elucidate the physico-chemical and energy characteristic of bamboo charcoal produced from two (2) different species which were Aur Kuning Bamboo and Beting Bamboo. Each bamboo was carbonized at a temperature of 300 to 400°C for a duration of two hours. It was found that the density and volatile matter content of bamboo charcoal have decreased, while the ash content, fixed carbon (FC) content and calorific value (CV) have increased after being converted into charcoal. The results show that Aur Kuning Bamboo has good quality bamboo charcoal in comparison with Beting Bamboo in terms of its FC and CV content. Based on the average value, the FC (82.10%) and CV of Aur Kuning Bamboo (27.23%) were higher than FC (70.42%) and CV (26.05%) of Beting Bamboo with 16.59% (FC) and 4.53% (CV) different. Statistical analysis showed that there was a significant effect for different species of bamboo and a significant correlation between physical and energy properties. In conclusion, Aur Kuning Bamboo harvested from Sarawak wild forest has a higher potential to be a feedstock for charcoal production that will be useful for various applications in the near future.

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INTRODUCTION

The issues of global warming and the effect on climate change have prompted a search for alternative, cleaner technologies in power generation and fuel production from renewable sources [1]. The depletion of fossil fuel resources and limited availability of fossil fuels also has increased the attention of many developing countries to investigate alternative sources from biomass [2].

Bamboo is a useful plant in the world and came from a family of grass. It is a fast-growing species of plant that can grow faster than wood. It can grow up to 4 feet per day. It is among the fastest-growing species of plant in the world and most of the population can be found in South Asia, Southeast Asia and East Asia including Malaysia [3]. Matured bamboo can be harvested in 4 to 8 years depending on the species of bamboo. Dwivedi et al. [4] reported that more than 1200 species of bamboo can be found all over the world and around 400 species mainly from China. The rapid growth of bamboo potentially can replace the depletion of woody biomass resources that can be used for renewable energy production and it is in line with current trends in green energy [5].

Bamboo is one of the potential feedstocks to substitute wood for charcoal production that can be produced via a pyrolysis process at high temperatures (800–1200◦C) [6-7]. It is a renewable energy resource, cost-effective and eco-friendly product that can be an alternative to fossil fuels. Charcoal produced from biomass like bamboo does not require long production times and causes less environmental pollution as compared to coal [5, 8]. Bamboo charcoal has been applied by agricultural communities in India to replace gas, oil and electricity [4]. Charcoal use is more widely for domestic purposes since it is a cleaner burning product with higher density than raw biomass as well as the smoke output has been reduced due to the increase of fixed carbon content [9]. It is also having an excellent adsorbent capacity that can be used to remove harmful gases, absorbs the unpleasant smell and being in water purification and wastewater treatment system [4]. Isa et al. [3,6] also reported that bamboo charcoal has an enormous surface area to mass ratio with a microporous structure which has great absorption properties that can hold (adsorb) a wide range of materials, chemicals, minerals, radio waves, humidity, odours and harmful substances. Bamboo charcoal surface area (300 m^2/g) is ten times greater than wood charcoal (30 m^2/g) and larger than multi-walled carbon nanotubes (200 m^2/g) [3]. Bamboo charcoal is a potentially cheaper alternative absorbent among carbon-based materials such as carbon nanotubes and, graphene that have a larger specific area and greater pore volume [10-11]. According to Asada et al. [12], bamboo charcoal has been used as an absorbent for indoor air pollution from chemicals.

The aim of this study is to elucidate the physico-chemical and energy characteristic of charcoal produced from two different species of bamboo. The effect on charcoal quality prepared using different part of bamboo was also studied.

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The statistical analysis was used to determine the factors influence the quality of bamboo and the selection of the most suitable species for charcoal production.

MATERIALS & METHODS

Preparation of raw materials for charcoal production

Two (2) species of wild bamboo harvested from selected Sarawak Forest area have been received from Sarawak Timber Industry Development Corporation (STIDC) which were Aur Kuning Bamboo (*Bambusa vulgaris* var striata) and Beting Bamboo (*Gigantochloa levis)*. Each species of bamboo received were divided into top, middle and basal part. Then, all these bamboo were cut/chopped into small sizes in a chip form.

Production of charcoal from raw bamboo

Every part of the bamboo for each bamboo species was carbonized via the pyrolysis process using pyrolyser (Figure 1). The carbonization process takes about two hours at a temperature of 300-400°C with an input capacity of two kg per batch. Then, the physical and chemical characteristics of each produced charcoal were determined.

Figure 1. Process of bamboo charcoal production using pyrolyser (a) Bamboo loaded into pyrolyser basket; (b) Pyrolysis using pyrolyser; (c) Bamboo charcoal.

Analysis of bamboo charcoal

Proximate analysis

A proximate analysis was carried out to determine the proximate amounts of substances in the material. For proximate analysis, the volatile matter content, ash content and fixed carbon were carried out using British Standard EN 14774 [13], British Standard EN 15148 [14], and British Standard EN 14775 [15], respectively.

Calorific value of bamboo charcoal

For calorific value (CV), the analysis was carried out using Bomb Calorimeter based on British Standard EN 14918 [16].

Statistical analysis

ANOVA (Microsoft Excel Data Analysis) was used for the statistical analysis of physico-chemical and energy characteristics according to species and part of bamboo.

RESULTS AND DISCUSSION

Characterization of raw bamboo

The physical properties of Aur Kuning and Beting Bamboo have been characterized. Detailed properties of both bamboos based on average value was shown in Table 1. The density of raw bamboo is important to determine its quality after converting it into charcoal where most of the volatile matter has been eliminated and reduce the density.

Table 1. Properties of Aur Kuning bamboo and Beting bamboo from Sarawak Forest.

Properties	Aur Kuning (*Bambusa vulgaris* var striata)	Beting (*Gigantochloa levis*)
Thickness (mm)	10.19	10.51
Density (kg/m^3)	938	785
Green moisture content (%)	46.00	40.20
Cellulose (%)	42.64	46.39
Hemicellulose (%)	30.37	25.75
Lignin (%)	22.88	32.25

Bamboo charcoal production efficiency

The bamboo charcoal production efficiency for both species of bamboo is shown in Figure 2. It was found that the top part of Aur Kuning bamboo charcoal has the highest production efficiency (28.00%) and the basal part of Beting bamboo has the lowest production efficiency (23.90%). According to Tippayawong et al. [17], the efficiency of charcoal production from bamboo is between 32.70% to 34.60%. While for wood the production efficiency is between 35.10% to 38.40%. For Beting bamboo, its shows that the efficiency of charcoal production is the least for the basal part. According to Bhonde et al. [18], the length of the node is smaller at the bottom and going to increase at the middle part and decrease again at the top portion especially for the uniqueness of bamboo. Due to that, the yield of charcoal is less for the bottom part of certain bamboo.

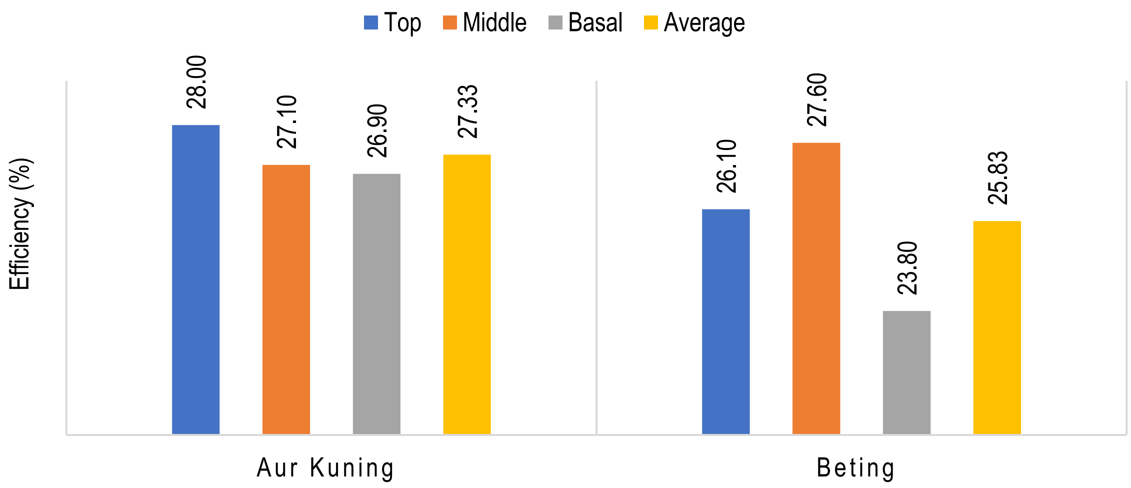

Figure 2. Bamboo charcoal production efficiency.

Comparison of raw bamboo after conversion into charcoal

The characteristic of raw bamboo before converting it into charcoal must be first carried out. All this data was used to compare characteristic properties before and after conversion to determine the product yield and its quality.

The physical properties, proximate analysis and calorific value (energy properties) of raw bamboo have changed significantly after converting it into bamboo charcoal.

Effect of physical properties on conversion of bamboo into charcoal

In Table 1, the density of raw bamboo was found to increase when the cellulose and lignin content decreased. The chemical composition contributed to the highest density in wood which is related to the bamboo as well which is in line with Wang et al. [19] findings. Li et al. [20] also reported that cellulose, hemicellulose and lignin content of bamboo contribute about 90% of the total bamboo mass. According to Park et al. [5], the density of all carbonized bamboo has decreased after carbonization at a temperature of between 200 to 400ºC. The decreasing density after converting it into charcoal has made it easier to transport compared to raw biomass [7].

The comparison of density after the raw bamboo is converted into charcoal is shown in Figure 3. The density has decreased by more than 45% for both species of bamboo. It is found that the basal part of Aur Kuning Bamboo has the highest density which was 428 kg/m^3 followed by the basal part of Beting Bamboo (414 kg/m^3). For average density, Beting Bamboo has the highest density (403 kg/m^3). The decreasing density is due to the removal of water content in raw bamboo during the pyrolysis process. Based on the result reported by Park et al. [21], the density of charcoal produced from Bamboo Semiliang is 360 kg/m^3 which is within the range reported for the highest and lowest density of all bamboo that has been used in this study.

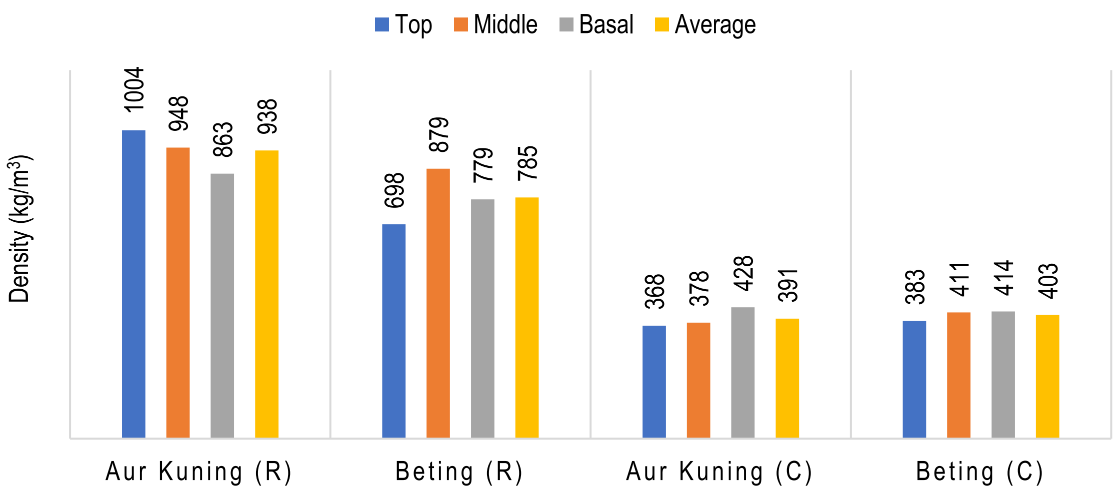

Figure 3. Comparison of density for raw bamboo and bamboo charcoal.

The density of bamboo is affected by the location and soil of the bamboo that was planted, the nutrient supply for bamboo growth and also the species of bamboo. According to Piouceau et al. [22], the amount of nutrient supply for bamboo growth affects the bamboo biomass. The high amount of nutrients will increase the bamboo biomass. It was found that the matured bamboo (four years) produced between 1.1 to 2.6 tons of dry matter/ha/year of bamboo for low nutrient supply and vice versa for high nutrient supply (1.4 to 3.4 tons dry matter/ha/year of bamboo). Besides that, Othman [23] has reported that the type of soil affected bamboo growth. Among the soil type, sandy clay loam areas (Renggam series) were the best, followed by shallow lateritic soil mixed with fine sandy clay (Jitra series). The application of organic fertilizer helped to improve the growth performance of these bamboo species. Due to that, it is important to choose the best soil type to increase the bamboo density. While for bamboo species, Oliveira et al. [24] have reported that different bamboo species have different basic densities. The density of *Bambusa pervariabilis, Dendrocalamus strictus* and *Bambusa vulgaris* were 346 kg/m^3, 651 kg/m^3 and 207 kg/m^3 respectively.

Comparison of proximate analysis of bamboo charcoal

Proximate analysis of raw materials is very important to determine the quality of charcoal produce. Four (4) important parameter that need to be measure were moisture content, volatile matter content, ash content and fixed carbon content. Moisture content (MC) that was measured for proximate analysis is the MC that was taken before the analysis being carried out.

Figure 4 to 7 shows the comparison of proximate analysis of raw bamboo and bamboo charcoal for different part of bamboo. The comparison was made to obtain the effect of converting its raw into high value-added products.

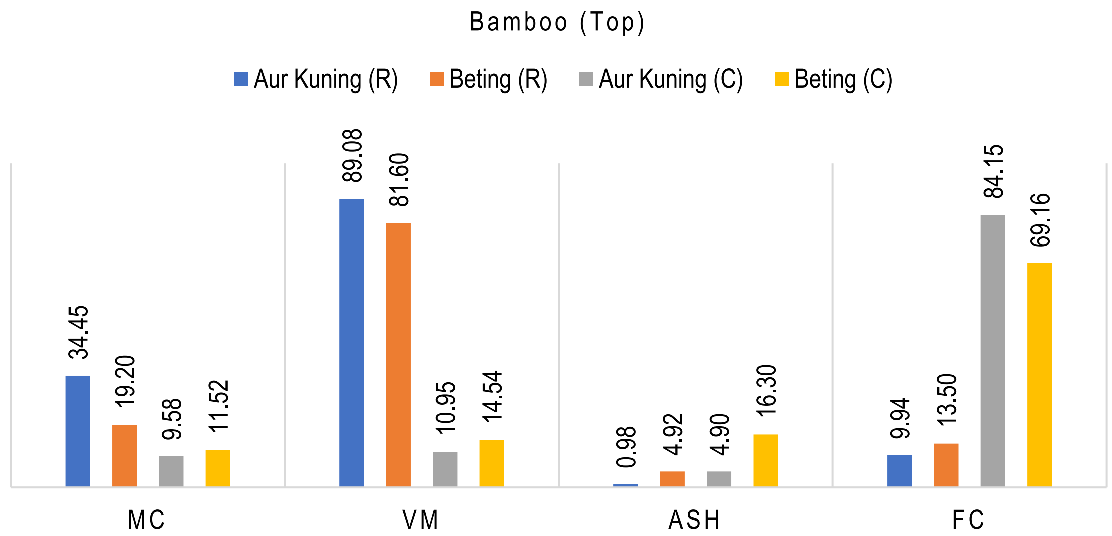

Figure 4. Proximate analysis of raw bamboo and bamboo charcoal using top part.

Figure 4 shows the comparison of proximate analysis for the top part of raw bamboo and bamboo charcoal. It was found that the raw bamboo for all bamboo species has high volatile matter (VM) content and moisture content (MC) and has low fixed carbon (FC) and ash content. After the conversion of raw bamboo into bamboo charcoal, the VM and MC content decreased while the FC and ash content increased. Among all bamboo studies, it shows that charcoal produced from Aur Kuning Bamboo has the highest FC (84.14%) and lowest VM (10.95%) after the conversion process. While Figure 5 shows significantly that the VM content has decreased and FC content has increased after converting the raw bamboo into charcoal for the middle part of the bamboo. It was found that charcoal produced from Aur Kuning Bamboo has the highest FC (81.22%) and the lowest VM (12.05%).

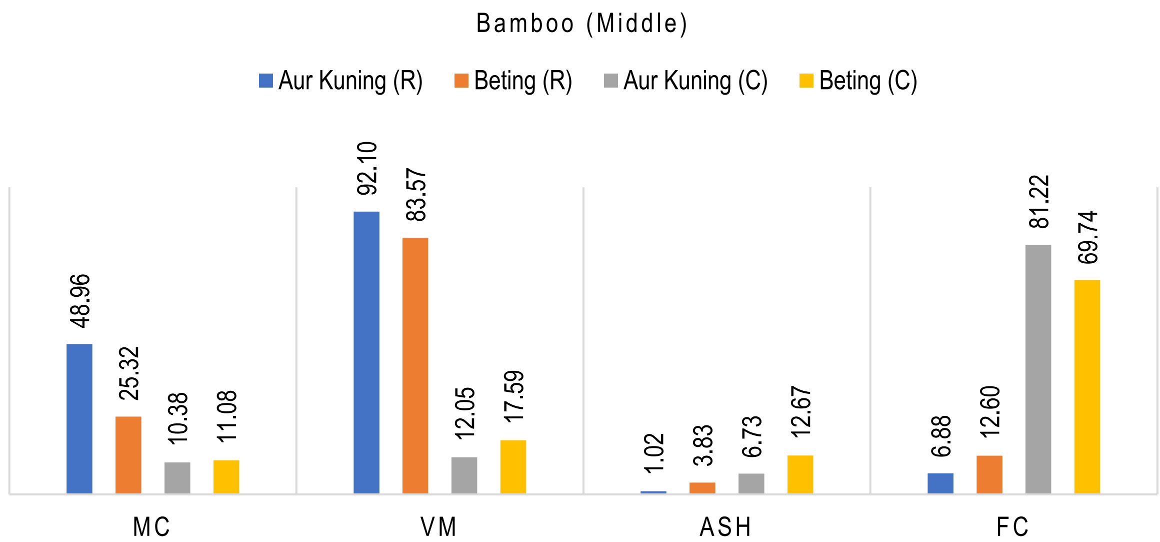

Figure 5. Proximate analysis of raw bamboo and bamboo charcoal using middle part.

The comparison of proximate analysis results for the basal part of raw bamboo after converting it into bamboo charcoal was shown in Figure 6. Like the top and middle parts, the VM and FC content has changed significantly. From the figure, it was found that the charcoal produced from Aur Kuning Bamboo has the highest FC (80.94%) and lowest VM (11.64%) after the conversion process. While Figure 7 shows the comparison of proximate analysis of average bamboo after converting it into bamboo charcoal. Average bamboo is the random mix of the top, middle and basal parts of the bamboo. It was found that charcoal produced from Aur Kuning Bamboo has the highest FC (82.10%) and the lowest VM (11.55%) after the conversion process.

Park et al. [21] reported that the ash content, volatile matter content and fixed carbon content of charcoal produced from Bamboo Semiliang were 8.17%, 30.53% and 56.62%. Komarayati & Gusmailina [25] reported that the charcoal produced from mixed bamboo has 5.61% ash content, volatile matter content of 19.40% and fixed carbon content of

72.26%. In comparison with our findings, it was found that the bamboo used in this study has higher FC content and lower VM content which shows our selected bamboo has high quality.

Among different parts of bamboo, the top part of Aur Kuning Bamboo has the highest FC content which is 84.15% and decreases towards the basal part with a percentage difference of 3.81% and it shows no significant different between a part of bamboo. Fixed carbon (FC) content is a very important parameter to obtain te high-quality charcoal. High FC contents show that the charcoal produced has high quality. For ash content, lower ash shows good quality bamboo charcoal. It was found that the top part of Aur Kuning Bamboo has the lowest ash content which is 4.90% and it is increasing to 7.42% for the basal part of bamboo with a 51.43% increase. Tippayawong et al. [17] reported that the range of fixed carbon and ash content for bamboo is 55.9 to 59.0% and 7.0 to 7.9% respectively. In comparison to the result reported in this study, it shows that both species of bamboo have higher FC content (69.16 to 84.15%) and indirectly produced a high quality of bamboo charcoal.

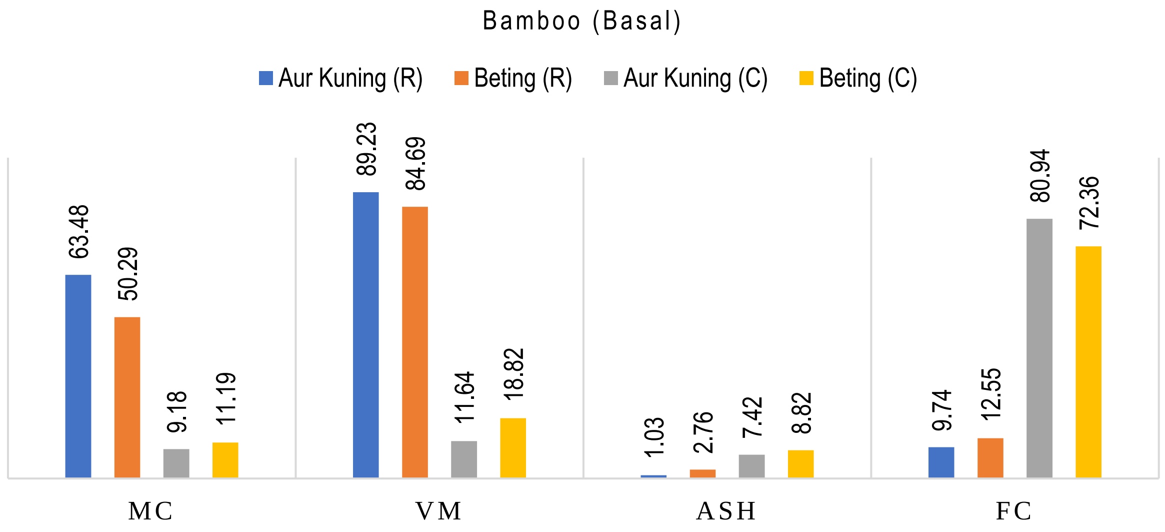

Figure 6. Proximate analysis of raw bamboo and bamboo charcoal using basal part.

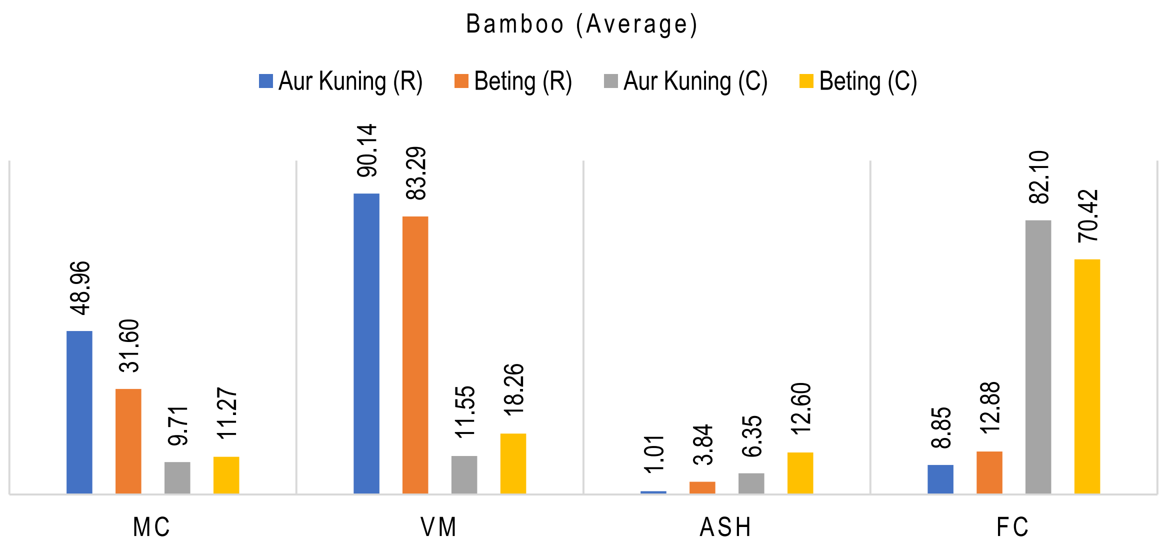

Figure 7. Proximate analysis of raw bamboo and bamboo charcoal using average part.

Effect of energy properties on conversion of bamboo into charcoal

The energy properties of bamboo charcoal were obtained by measuring its calorific value (CV). A higher CV means the bamboo charcoal has higher quality. Figure 8 shows the CV before and after the bamboo was converted into charcoal.

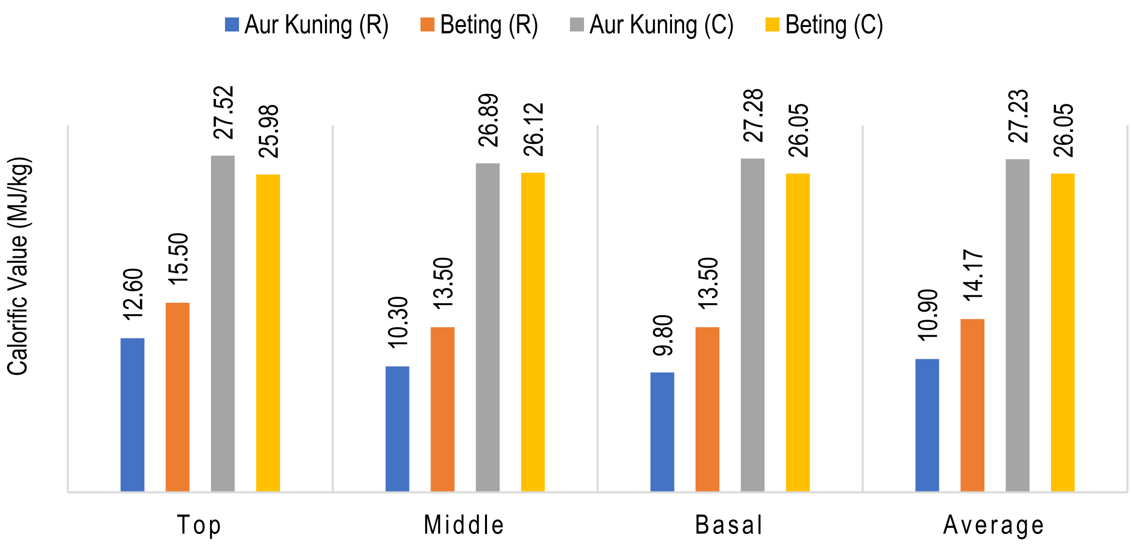

Figure 8. Calorific value of raw bamboo and bamboo charcoal.

It was found that the calorific value (CV) increased after conversion from raw bamboo to bamboo charcoal. From Figure 8, the bamboo charcoal produced from the top part of Aur Kuning Bamboo has the highest CV (27.52 MJ/kg) with the top part of Beting Bamboo having the lowest CV (25.98 MJ/kg). Charcoal produced from Bamboo Sembilang has a CV content of 28.41 MJ/Kg [21] which is higher than the range of CV for bamboo that has been selected in this study (25.98 to 27.52 MJ/kg) with a 3.23% difference which is not significant. In general, calorific value (CV) increased when raw bamboo was converted into bamboo charcoal. High CV content shows a high quality of bamboo charcoal. The CV of wood and bamboo were 22.5 MJ/kg and 23.1 MJ/kg respectively [17]. This reported result is lower than the CV of charcoal produced using both selected bamboo. Besides that, the high ash content has been verified to reduce the calorific value depending on the type of biomass, a different part of the same species, moisture content and type of soil to grow the biomass materials [26]. In this study, the Aur Kuning Bamboo has a CV value of 27.52 MJ/kg with an ash content of 4.90% for the top part and the CV value has decreased to 26.89 MJ/kg with an increasing value of ash content (6.73%) for the middle part. It's proven that when ash content increased the CV value decreased. The result of charcoal production using both bamboos was compared with previous research that has been carried out by other researchers (Table 2).

Table 2. Comparison of Bamboo Charcoal Properties (Proximate).

	Biomass	FC (%)	VM (%)	Ash (%)	CV (MJ/kg)	Reference
1.	Bamboo	69-84	11-19	5-16	26-28	This study
2.	Bamboo	56-59	26-28	7-10	23	[17]
3.	Wood	54-60	22-32	6-10	23	[17]
4.	Wood	72.7	20.7	1.7	28.0	[27]
5.	Bamboo	78.0	15.0	3.0	32.0	[5]
6.	Coconut flesh	45.0	50.0	4.6	34.0	[28]
7.	*Pinus radiata*	84.0	11.0	3.3	32.1	[29]
8.	Mangrove	69.3	21.6	1.6	29.8	[30]
9.	Meranti	86.2	8.4	2.9	30.4	[30]
10.	Maize stem	68.4	15.6	16	26.7	[7]
11.	*Shorea robusta*	66.2	29.3	4.5	28.1	[7]

Statistical analysis

Statistical analysis of charcoal produced using different part of Aur Kuning bamboo and Beting bamboo were carried out using ANOVA with single factor. Summary findings of ANOVA Single Factor analysis is shown in Table 3. The interaction between factors were done based on its F and P value where the F value less than F critical value shows there is no significant different. P value more than 0.05 (α-value) also shows there is no significant different.

Table 3. Summary of ANOVA Single Factor analysis.

Properties	Different Bamboo Species			Different Portion		
	F	F_{crit}	P	F	F_{crit}	P
Production efficiency	3.37	5.99	0.12	0.79	6.59	0.56
Density	0.60	5.99	0.47	3.37	6.59	0.14
Volatile matter	34.41	5.99	0.00	0.15	6.59	0.93
Fixed carbon	134.95	5.99	0.00	0.01	6.59	0.99
Ash content	14.93	5.99	0.01	0.08	6.59	0.97
Calorific value	78.82	5.99	0.00	0.03	6.59	0.99

Table 3 shows all the properties of bamboo charcoal that has been studied. The F value is more than F critical value and the P value is less than 0.05 for different species of bamboo. This finding shows that species of bamboo has significant effect on properties of bamboo charcoal produced. While for different portion of bamboo, the F value is less than F critical value and P value is more than 0.05. This finding shows that the portion of bamboo has no significant effect on properties of bamboo charcoal produced.

Selection of suitable bamboo for charcoal production

Based on the result reporting for proximate analysis and calorific value of bamboo charcoal produced, rating of the quality of charcoal has been made based on the most important criteria to choose the most suitable species of bamboo which are high FC content, low ash content and high calorific value (CV). The rating was made by giving a value of 1 for the best quality and a value of 2 for the poorest quality of bamboo charcoal. It shows that for FC content and CV the highest quality has an increasing value while for ash content the highest value has a decreasing value. The best quality has the lowest total rating which is suitable for bamboo charcoal production.

Table 4 shows the rating of bamboo charcoal produced using the top, middle, basal and mixed parts of bamboo based on the proximate analysis. It was found that Bamboo Aur Kuning has the highest rating for fixed carbon (FC) content, ash content and calorific value. While Bamboo Beting has the lowest rating. Overall, the top part of Bamboo Aur Kuning shows the best quality of bamboo charcoal based on its proximate analysis properties and calorific value that has been studied.

Overall ratings to determine the suitable bamboo species based on proximate analysis and calorific value were shown in Table 5. It was found Bamboo Aur Kuning has the best quality of bamboo charcoal.

Table 4. Rating of proximate analysis of charcoal from top part of bamboo.

Types of bamboo	FC	Ash	CV	Total rating
		Top		
Aur Kuning	84.15 (1)	4.90 (1)	27.52 (1)	3
Bamboo Beting	69.16 (2)	16.30 (2)	25.98 (2)	6
		Middle		
Bamboo Aur Kuning	81.22 (1)	6.73 (1)	26.89 (1)	3
Bamboo Beting	69.74 (2)	12.67 (2)	26.12 (2)	6
		Basal		
Bamboo Aur Kuning	80.94 (1)	7.42 (1)	27.28 (1)	3
Bamboo Beting	72.36 (2)	8.82 (2)	26.05 (2)	6
		Average		
Bamboo Aur Kuning	82.10 (1)	6.35 (1)	27.23 (1)	3
Bamboo Beting	70.42 (2)	12.60 (2)	26.05 (2)	6

Table 5. Comparison of bamboo charcoal produced from different species of bamboo using different part of bamboo based on its proximate analysis and calorific value.

Types of bamboo	Top	Middle	Basal	Average	Total rating
Bamboo Aur Kuning	3	3	3	3	12
Bamboo Beting	6	6	6	6	24

CONCLUSIONS

The quality of bamboo charcoal was verified based on its volatile matter (VM) content, ash content, fix carbon (FC) content and calorific value (CV) as well as production efficiency. Based on the average value, the VM content for both bamboos was decreased when the raw bamboo (83.3–90.1%) was converted into bamboo charcoal (11.6-18.3%). The higher-quality of bamboo charcoal has less VM content. Ash content increased when raw bamboo (1.0-3.8%) was converted into bamboo charcoal (6.4-12.6%). Low ash content shows a high quality of bamboo charcoal. Fixed carbon content (FC) also increased when raw bamboo (8.9-12.9%) was converted into bamboo charcoal (70.4-82.1%). High FC content shows high-quality bamboo charcoal. According to ANOVA Single Factor analysis, species of bamboo have a significant effect on the quality of bamboo charcoal. Due to that, it is important to select suitable bamboo species because different bamboo has different physical, chemical as well as morphological structures. However, a different portion of bamboo has no significant effect on bamboo charcoal production. So, all parts of bamboo can be mixed together to produce bamboo charcoal. Based on the total rating to determine the best suitable species for bamboo charcoal production, it was found that Aur Kuning Bamboo has the highest total rating.

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