Characterization of branch waste of several tropical fruit tree species as considerations for bioenergy resources

D Irawati¹*, S Higeta², S Wedatama², F Ishiguri² and S Yokota²

¹Faculty of Forestry, Gadjah Mada University, Indonesia
²Faculty of Agriculture, Utsunomiya University, Japan

*Corresponding author’s e-mail address: dirawati@ugm.ac.id

Abstract. The aims of this research were to analyse the bio-energy properties of tree branches and determine the appropriate conversion process for the fuel source use of each species. Bio-energy properties, such as proximate analysis, calorific value, firewood value index, and hydrolysis rate of wood, and chemical component content were evaluated for branches of 11 fruit tree species (Cacao, Durian, Java plum, Rose apple, Guava, White leadtree, Mango, Gnetum, Jackfruit, Rambutan, Strawberry tree) planted in Indonesia. Among all 11 species, Rambutan, Mango, and Java plum were the best 3 species for firewood feedstock, with the score 176.6, 169.2, and 163.8 respectively. While Mango, White leadtree, and Jackfruit were the best three species for liquid bio-fuel feedstock, with the score 91.1, 86.6, and 78.0 respectively. The branches of Durian and Gnetum can be used for purposes other than bio-energy due to their low score in both two groups.

Keywords: bio-energy properties, tree branch, calorific value, enzymatic saccharification, firewood, liquid bio-fuel

1. Introduction
Biomass is a renewable energy resource derived from carbonaceous materials. Biomass worldwide ranks fourth as a source of energy and provides approximately 14% of the world's energy needs. In developing countries, such as Indonesia, the average use of biomass as an energy source can reach 35% of its total energy needs [1]. Biomass is used as a household fuel for cooking, transportation, and electricity and is also used for industry. Among the various renewable energy resources, biomass has the advantage of being the only organic material; therefore, it can be converted into thermal energy (as firewood) and also into liquid fuel (bio-fuel) that can be stored easily [2]. The use of biomass as a fuel will provide benefits to a community as long as the community takes care of the environment. During the utilization of biomass as an energy, CO₂ is released into the atmosphere; however, CO₂ is absorbed during growth. Therefore, the utilization of biomass as energy entails a short CO₂ cycle and does not contribute to the greenhouse effect.

Firewood consists of any unprocessed woody biomass used to fuel a small fire, most often for cooking or warmth, and usually comes from dead woody material and small trees [3]. In the past few years, bio-fuel programmes have gained new momentum as a result of rising prices of fossil fuels as well as the advent of flex-fuel vehicles, which can utilize different percentages of ethanol blended with gasoline. Development of technologies for multiple-fuel conversion options make biomass a cheap and effective fuel.
Trees are one of the biomass producers in the world and consist of stems, branches, foliage, fruit, and roots. In Indonesia, there are many fruit trees in home gardens as well as commercial plantations, and farmers usually plant various woody species in the community forest area or in their gardens. They plant species for timber production as well as species that provide non-wood products, such as species with fruit that can be consumed. Because of their function as a fruit producer, farmers keep the trees growing on their land for a considerable period of time, pruning to reduce the amount of branching, smoothing the shape, or taking some branches for fuel wood. Branches can be taken continuously from a tree without cutting it down. For energy utilization, tree branches can be converted into liquid, solid, and gas fuels by using physical, chemical, or biological conversion processes. The knowledge of their characteristics is essential for effective utilization of biomass fuel, and the chemical properties of each material will greatly assist the determination of the biomass conversion process. Biomass with high lignin content would be better when used as firewood (direct combustion) because of the high calorific value of lignin [4]. However, biomass with high lignin content would be difficult to convert into liquid bio-fuels such as ethanol and methanol because of the barrier of lignin to cellulose hydrolysis [5-6].

To decide on the conversion process, several characteristics of the biomass should be known. For biomass selection for firewood, the calorific value and ash content or volatile matter content as well as the chemical component content are very important [7]. On the other hand, for utilization as liquid fuel, yield of glucose content by the hydroxylation process is also an important criterion. The analytic hierarchy process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales [8, 9]. The comparisons are made using a scale of absolute judgements that represents how much more one element dominates another with respect to a given attribute. The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and then adding for all such nodes. In a previous study, AHP analysis was used for assessing sustainability of wood-based bio-energy production [10]. The objectives of this study are to analyse the properties (chemical contents, proximate analysis, calorific value, and the rate of hydrolysis) of the branch wood of 11 tree species planted in Indonesia and assess their potential as an energy source by using AHP analysis.

### 2. Materials and methods

#### 2.1 Materials

One or 2 branches from 3 trees of 11 fruit tree species (2.9-7.6 cm in diameter) were collected from home gardens or community forests around Yogyakarta, Indonesia (Table 1). These species are very popular among farmers as well as the local people in Indonesia for yielding fruit. After collecting the branches, the bark was removed, and only the wood was used for the following experiments.
Table 1. List of the samples species

| No | Common name    | Scientific name                  | Family         | Diameter (cm) |
|----|----------------|----------------------------------|----------------|--------------|
| 1  | Cacao (C)      | *Theobroma cacao* L.             | Sterculiaceae  | 3.5 ± 0.4    |
| 2  | Durio (D)      | *Durio zibethinus* Murray        | Bombacaceae    | 5.4 ± 0.8    |
| 3  | Java-plum (Jp) | *Syzygium cumini* (L.) Skeels    | Myrtaceae      | 7.2 ± 0.4    |
| 4  | Rose apple (Ra)| *Syzygium jambos* (L.) Alston   | Myrtaceae      | 6.1 ± 0.5    |
| 5  | Guava (G)      | *Psidium guajava* L.             | Myrtaceae      | 4.1 ± 0.2    |
| 6  | White leadtree (Wl)| *Leucaena leucocephala* (Lam.) de Wit | Fabaceae | 5.1 ± 0.5 |
| 7  | Mango (M)      | *Mangifera indica* L.            | Anacardiaceae  | 7.6 ± 0.5    |
| 8  | Gnetum (Gg)    | *Gnetum gnemon* L.               | Gnetaceae      | 3.8 ± 0.4    |
| 9  | Jackfruit (J)  | *Artocarpus heterophyllus* Lam.  | Moraceae       | 6.6 ± 0.4    |
| 10 | Rambutan (R)   | *Nephelium lappaceum* L.         | Sapindaceae    | 3.2 ± 0.6    |
| 11 | Strawberrytree (S)| *Muntingia calabura* L.        | Elaeocarpaceae | 2.9 ± 0.4    |

2.2 Chemical contents of wood
The sample branches were milled by a speed rotary mill (P-14, Fritsch, Germany), and then the wood powder was sieved. Wood powder of 40 to 80 mesh in size was used for the experiment, and the samples were dried in an oven at 45°C. The content of ethanol-toluene-soluble extractives, holocellulose, α-cellulose, Klason lignin, and acid-soluble lignin was determined according to the method previously described [11]. The chemical content of the wood was determined using 3 replications for each sample.

2.3 Proximate analysis of wood
The ash, volatile matter, and fixed carbon content was analysed according to American Standard of Testing Materials (ASTM) D3172-4 [12]. The ash content was measured by weighing the residual ash after heating 2 g of the original sample at 600 °C for 4 hours. The volatile matter content was determined by using a furnace (Thermo Line, United States of America). A total of 2 g of the sample was heated at 900 °C for 15 minutes. After cooling, samples were weighed, and the difference between the initial sample weight and weight after heating was then determined for calculating the weight of volatile matter. The fixed carbon content was determined by subtracting the percentages of moisture, volatile matter, and ash from a sample.

2.4 Analysis of basic density and calorific value
Fan-shape specimen was obtained from each branch as basic density (BD) sample. The green volume of each sample was determined by water displacement. After determination of green volume, the samples were dried in an oven at 103±2 °C to constant weight. The oven dried samples were then stored in a desiccator containing dry silica gel after which they were weighed in an analytical balance. BD was determined to divide the values of oven-dried weight by green volume measured by water displacement method [13].

A 1-g sample was oven-dried until a constant weight at 80 °C was obtained, and the sample was then burned in an oxygen bomb calorimeter apparatus (Parr 1341, United States of America) to measure its calorific value [14]. The calorific value was adjusted on the basis of the calorific value of benzoic acid.
2.5 Firewood value index

In the present study, the firewood value index (FVI) was used as the value of the suitability of biomass as fuel wood [7][15]. The firewood index was calculated by the following formula:

\[
FVI = \frac{\text{calorific value} \times \text{density}}{\text{ash content}}
\]

The calorific value and moisture content of the sample varied in each sample; therefore, the moisture content of the sample at testing was used for adjustment.

2.6 Hydrolysis of wood

The commercial enzyme Meiselase (Meiji Seika, Japan) was used to saccharify the samples. A sample (size 40-80 mesh) of 200 mg was saccharified at 40 °C for 48 hours according to the method previously reported [16]. Hydrolysis weight loss was calculated by comparing the sample weight before and after hydrolysis. The wood hydrolysis rate was measured 3 times. The type and concentration of monosaccharides that formed were analysed using high performance liquid chromatography (HPLC) according to a previous method [16], and each sample was analysed with 1 replication.

2.7 Data analysis

The data were analysed by one-way analysis of variance (ANOVA) to clarify the differences among the wood species. In addition, Tukey-Kramer analysis was also applied to find the significant difference at a 5% confidence level among wood species. Pearson correlation analysis was used to examine the correlations among the parameters and to eliminate the number of parameters used in the analytic hierarchy process (AHP) analysis. AHP analysis was applied to determine the suitability between wood species and their usage as energy sources (ranking each wood species). The steps for the AHP analysis were as follows:

1. Developing the criteria for each usage as energy sources (for firewood or liquid bio-fuel)
2. Developing a pairwise comparison matrix for each criterion
3. Calculating and checking the consistency ratio
4. Normalizing the resulting matrix
5. Averaging the values in each row to obtain the corresponding rating.

3. Results and Discussion

3.1 Chemical contents of wood

The mean value of the chemical content is presented in Table 2. The extractives are a group of chemicals mainly consisting of fats, fatty acids, fatty alcohols, phenols, terpenes, steroids, resin acids, rosin, waxes, and many other minor organic compounds [17]. The contents and composition of extractives vary depending on the wood species, geographical location, and position in the tree [18]. There is a positive correlation between the extractives content and the calorific value of wood, suggesting that, theoretically, wood with high extractives content has better characteristics for firewood use [4]. In the present study, the content of ethanol-toluene extracts ranged from 1.0 to 6.9%, with the highest content found in Mango branches. These results for ethanol-toluene extracts content were in the range of extractives content of tropical timbers, which can reach up to 20% of the dry weight of the wood [4]. On the other hand, the results obtained in some species, such as Jackfruit and Mango, were different than those found in previous studies. The extractive content in Jackfruit and Mango was found to be 7.7% and 2.8% previously, respectively [19-20]. The differences in the content of these extractives were perhaps caused by the samples used in this study, taken from branches.
Table 2. Chemical contents of branches from 11 species

| Species | Ethanol-toluene extracts (%) | Holocellulose (%) | α-cellulose (%) | Hemicellulose (%) | Klason lignin (%) | Acid soluble lignin (%) |
|---------|-----------------------------|-------------------|----------------|------------------|------------------|------------------------|
| C       | 3.4 ± 0.1 c                 | 83.6 ± 0.1 bc     | 41.2 ± 0.1 a   | 42.4 ± 0.2 d     | 16.0 ± 0.8 b     | 2.5 ± 0.2 cd           |
| D       | 1.7 ± 0.1 ab                | 78.6 ± 0.1 a      | 43.7 ± 0.4 b   | 34.9 ± 0.3 b     | 16.2 ± 0.3 b     | 3.1 ± 0.0 d            |
| Jp      | 4.4 ± 0.1 d                 | 81.5 ± 1.0 b      | 47.8 ± 0.3 cd  | 33.6 ± 0.7 ab    | 25.4 ± 0.0 e     | 2.5 ± 0.0 cd           |
| Ra      | 1.5 ± 0.4 ab                | 83.9 ± 0.4 bc     | 49.2 ± 0.2 d   | 34.7 ± 0.7 ab    | 28.0 ± 0.3 f     | 1.6 ± 0.1 ab           |
| G       | 2.5 ± 0.2 b                 | 79.7 ± 0.4 ab     | 43.0 ± 0.0 ab  | 36.6 ± 0.3 bc    | 25.0 ± 0.0 e     | 2.3 ± 0.0 c            |
| Wl      | 2.0 ± 0.2 b                 | 83.6 ± 1.1 bc     | 43.7 ± 1.0 b   | 39.9 ± 2.0 cd    | 22.0 ± 0.3 d     | 1.5 ± 0.0 a            |
| M       | 6.9 ± 0.5 e                 | 79.7 ± 0.4 ab     | 41.2 ± 0.6 a   | 38.5 ± 1.0 c     | 14.4 ± 0.5 a     | 3.6 ± 0.1 e            |
| Gg      | 1.0 ± 0.1 a                 | 85.2 ± 0.2 c      | 48.1 ± 0.7 cd  | 37.1 ± 0.5 bc    | 20.1 ± 0.1 cd    | 2.6 ± 0.0 cd           |
| J       | 2.1 ± 0.0 b                 | 84.3 ± 0.0 c      | 46.9 ± 0.8 c   | 37.4 ± 0.8 bc    | 24.3 ± 0.1 e     | 1.7 ± 0.1 ab           |
| R       | 1.0 ± 0.0 a                 | 83.2 ± 0.4 bc     | 51.7 ± 0.2 e   | 31.5 ± 0.3 a     | 19.4 ± 0.0 c     | 2.8 ± 0.1 d            |
| S       | 1.3 ± 0.0 ab                | 82.6 ± 1.4 bc     | 41.9 ± 0.6 ab  | 40.6 ± 0.8 cd    | 21.3 ± 0.3 d     | 1.8 ± 0.1 b            |

Species codes refer to Table 1. The same alphabet letter followed by mean and standard deviation in each column shows no significant differences between wood species by Tukey–Kramer test at the 5% level.

The highest content of holocellulose, α-cellulose, and hemicellulose was found in Gnetum and Jackfruit, Rambutan, and Cacao, respectively (Table 2). The results of holocellulose content ranged from 78.6 to 85.2%, and a significant difference among the species was found. The content of α-cellulose ranged from 41.2 to 51.7% and also showed significant differences among the species. Cellulose is a polymer of the straight monomer D-glucose with β-1,4-glycosidic linkages [21]. The cellulose content of normal hardwood ranges from 40 to 45% and is higher in tension wood (50-65%) [22]. Theoretically, the difference between the holocellulose and α-cellulose content can be regarded as hemicellulose content. From the calculations, the hemicellulose content of all 11 species ranged from 31.5 to 42.4% (Table 2). The main composition of hemicellulose in hardwood is xylan [23], while holocellulose is a carbohydrate in the wood that can be hydrolysed as a monosaccharide for bio-fuel material. Woods with high holocellulose content, therefore, are estimated to be suitable as bio-fuel feedstock.

The Klason lignin content ranged from 14.4 to 28.0%, with the highest content found in Rose apple wood. The Klason lignin content of normal hardwood ranges from 19 to 30%, while the content is lower in tension wood [24]. The low Klason lignin content of Mango may be due to the formation of the tension wood in the branch. The highest content of acid-soluble lignin (3.6%) was found in the Mango wood, whereas the lowest content of acid-soluble lignin (1.5%) was found in the White leadtree wood. Statistically, there was a significant difference between the value of Klason lignin and acid-soluble lignin in each species (Table 2). Similar to the extractive levels, there is a positive correlation between the lignin content and wood calorific value [4]. On the other hand, some studies have also reported that lignin content inhibits the hydrolysis of cellulose for producing bio-ethanol [5-6].
3.2. Proximate contents

Table 3. Basic density, proximate analysis results, calorific value, and firewood value index of branches from 11 species

| Species          | Basic density (g/cm³) | Ash (%)   | Volatile matter (%) | Fixed carbon (%) | Calorific value (kJ/g) | FVI  |
|------------------|-----------------------|-----------|---------------------|------------------|------------------------|------|
| C                | 0.28 ± 0.03           | a         | 1.7 ± 0.3           | bc                | 71.5 ± 3.7              | ab   |
| D                | 0.26 ± 0.01           | a         | 2.5 ± 0.7           | bc                | 80.2 ± 1.9              | a    |
| Jp               | 0.53 ± 0.01           | c         | 1.2 ± 0.1           | c                 | 73.8 ± 1.6              | ab   |
| Ra               | 0.63 ± 0.05           | c         | 2.2 ± 0.1           | bc                | 68.1 ± 4.0              | a    |
| G                | 0.60 ± 0.03           | bc        | 6.5 ± 1.7           | a                 | 77.2 ± 5.3              | a    |
| WI               | 0.48 ± 0.01           | bc        | 2.6 ± 0.2           | bc                | 83.9 ± 3.1              | a    |
| M                | 0.45 ± 0.03           | bc        | 1.2 ± 0.1           | c                 | 82.4 ± 2.1              | a    |
| Gg               | 0.47 ± 0.00           | c         | 3.2 ± 0.1           | bc                | 75.7 ± 2.6              | a    |
| J                | 0.45 ± 0.01           | bc        | 2.0 ± 0.0           | bc                | 65.4 ± 2.1              | b    |
| R                | 0.53 ± 0.03           | c         | 1.0 ± 0.2           | c                 | 81.6 ± 0.8              | a    |
| S                | 0.42 ± 0.07           | b         | 1.4 ± 0.2           | c                 | 68.4 ± 3.0              | ab   |

Species codes refer to Table 1. The same alphabet letter followed by mean and standard deviation in each column shows no significant differences between wood species by Tukey–Kramer test at the 5 % level.

The results of proximate analysis including the ash, volatile matter, and fixed carbon content are presented in Table 3. The mean values of ash content in the 11 wood species used in this study ranged from 1.0 to 6.5%, and significant differences in ash content were found among the species. The highest ash content was found in Guava branches. Ash is a mineral residue from the combustion process, and it is usually expressed as the ash content. The ash content of wood from Agathis borneensis, Gonystylus sp., Shorea negroensis, Dryobalanops rappa, Dipterocarpus sp., Upuna borneensis, and Shorea sp. grown in Brunei (ranging from 0.45 to 1.13%) was lower than that of the 11 species used in the present study [25]. High ash content in wood can reduce the calorific value of the wood because ash is a non-combustible content of biomass [2]. In addition, fuel wood with high ash content is undesirable because formed ash can cause disposal problems [26].

The mean volatile matter content of the 11 wood species used in this study ranged from 65.4 to 83.9% (Table 3). This range is narrower than that in Eucalyptus hybrids, Acacia auriculiformis and Casuarina equisetifolia (in the range of 82-86%) [14]. There were significant differences in the content of volatile matter among the 11 wood species, with the highest volatile matter content found in White leadtree branches. During the combustion process of biomass (wood), volatile matter comes out first and is burned to form a gas. Therefore, wood with high volatile matter content will produce a large amount of gas when it is burned.

In general, wood with a high fixed carbon content has a higher calorific value [26]. The mean value of the fixed carbon content ranged from 13.5 to 32.6% (Table 3). The fixed carbon content in this study was higher or in the range of the fixed carbon content (12-16%) of Eucalyptus hybrid, Acacia auriculiformis and Casuarina equisetifolia [13]. Significant differences in the fixed carbon content were found among the 11 species, suggesting that calorific value might be different among species.

3.3. Basic density, calorific value, and firewood value index

The calorific value is a very important parameter for firewood, and it is known that calorific value is positively correlated with the basic density of the wood [27]. The firewood value index (FVI) can be used for an assessment of the suitability for firewood and is affected by the calorific value, basic density, and ash content [15]. Table 3 shows the results of the present study.

Basic density ranged from 0.28 to 0.63 g/cm³, and the highest basic density was observed in Rose apple branches. Values of basic density obtained in the present study were in the range of basic density of stem wood reported by previous researchers [28]. In addition, significant differences in basic density were found among species.
The mean calorific value of air-dried wood ranged from 9.2 to 21.6 kJ/g (Table 3). Based on the statistical analysis, the calorific value of wood showed significant differences among the wood species. The branches of Jackfruit showed the highest calorific value. The calorific values of this study were similar to the calorific value of some other tropical hardwood species with 4761 cal/g (19.9 kJ/g) [27][29-30].

Wood with a high FVI is favoured as firewood. A high calorific value, high wood density, and low ash content results in a higher FVI value [15]. The mean FVI value of 11 species used in the present study ranged from 1596 to 8659 (Table 2). The range of FVI obtained in the present study was narrower than that obtained in 16 species of woody trees and 23 fodder plants from Sikkim, India (448-22678) reported by Chettri and Sharma [15].

### 3.4. Hydrolysis weight decrease and monosaccharide content

Table 4. Hydrolysis weight decrease and monosaccharides content of branches from 11 species

| Species | Hydrolysis weight decrease (%) | Monosaccharide (g/100g sample) |
|---------|--------------------------------|---------------------------------|
|         |                                | Glucose | Xylose | Galactose | Arabinose |
| C       | 7.5 ± 1.1 c                    | 5.78    | 0.58   | 1.22      | 0.16      |
| D       | 3.5 ± 0.4 ab                   | 3.08    | 0.33   | 0.60      | 0.07      |
| Jp      | 2.7 ± 0.2 ab                   | 7.04    | 0.35   | 3.91      | 0.03      |
| Ra      | 4.3 ± 0.2 ab                   | 7.49    | 0.13   | 2.35      | 0.05      |
| G       | 6.0 ± 0.4 bc                   | 10.74   | 0.58   | 4.58      | 0.06      |
| Wl      | 14.5 ± 1.2 d                   | 18.16   | 1.28   | 2.21      | 0.10      |
| M       | 16.7 ± 0.8 d                   | 13.09   | 0.69   | 0.73      | 0.21      |
| Gg      | 5.0 ± 0.4 b                    | 0.44    | 0.22   | 0.37      | 0.04      |
| J       | 9.2 ± 0.6 c                    | 13.59   | 0.98   | 3.68      | 0.10      |
| R       | 3.7 ± 0.6 ab                   | 2.70    | 0.52   | 1.10      | 0.07      |
| S       | 2.3 ± 0.2 a                    | 6.69    | 0.43   | 3.74      | 0.10      |

Species codes refer to Table 1. The same alphabet letter followed by mean and standard deviation in each column shows no significant differences between wood species by Tukey–Kramer test at the 5% level.

The suitability of wood as a raw material for liquid bio-fuel can be estimated by the hydrolysis weight decrease and by reducing sugar content. One of the reducing sugars, glucose, which is derived from the hydrolysis of the cellulose and part of the hemicellulose, is fermented to alcohol (ethanol). Table 4 shows the mean hydrolysis weight decrease rate for the 11 species, which ranged from 2.3 to 16.7%. The hydrolysis rate of the 11 species was higher or in the range of the hydrolysis weight decrease of species from Japan, which ranged from 1.5 to 8.6% [11]. Based on statistical analysis, there was a significant difference in the hydrolysis weight decrease among the wood species. The highest hydrolysis weight decrease was found in the Mango branches, whereas the lowest was found in the Strawberry tree. Wood with a higher hydrolysis rate can be regarded as a suitable raw material for bio-ethanol production through the fermentation process.

The monosaccharide content (glucose, xylose, arabinose, and galactose) results based on biomass dry weight are shown in Table 4. The glucose content ranged from 0.44 to 18.16 g/100 g of sample. The xylose, arabinose, and galactose content ranged from 0.22 to 1.28 g/100 g of sample, from 0.04 to 0.21 g/100 g of sample, and from 0.37 to 4.58 g/100 g of sample, respectively. The glucose content of these 11 wood species were greater than in other timbers from Japan, which ranged from 1.8 to 3.0 g/100 g of sample [11]. The glucose content was higher than that of other monosaccharides, as glucose is the main component of the monomer of cellulose, while the other monosaccharides are constituents of hemicellulose. The highest content of glucose was yielded by White leadtree, and high glucose content is a good indication of the suitability of the wood as a raw material for making liquid bio-fuels.
3.5. Suitability as a fuel

Table 5. Pearson correlation coefficients between parameters

| Parameter | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q |
|-----------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Firewood  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Chemical  | H | -0.22 | -0.24 | -0.17 | 0.03 | 0.30 | -0.13 | 0.31 | 1.00 |   |   |   |   |   |   |   |   |   |
|           | I | 0.24 | -0.44 | -0.10 | -0.19 | -0.49 | 0.53 | -0.05 | 0.11 | 1.00 |   |   |   |   |   |   |   |   |   |
|           | J | -0.17 | 0.47 | 0.13 | 0.17 | 0.40 | -0.47 | -0.02 | -0.33 | -0.97 | 1.00 |   |   |   |   |   |   |   |   |   |
|           | K | 0.18 | -0.15 | 0.01 | -0.11 | -0.25 | 0.29 | -0.16 | 0.20 | 0.32 | -0.35 | 1.00 |   |   |   |   |   |   |   |   |
|           | L | 0.36 | 0.02 | 0.45 | -0.48 | -0.09 | 0.31 | 0.26 | -0.61 | 0.22 | -0.07 | 0.23 | 1.00 |   |   |   |   |   |   |   |   |
| Bio-fuel  | M | 0.57 | -0.06 | -0.44 | 0.45 | -0.34 | 0.10 | -0.05 | -0.03 | 0.42 | -0.39 | 0.42 | 0.12 | 1.00 |   |   |   |   |   |   |   |   |
|           | N | 0.38 | -0.07 | -0.38 | 0.37 | 0.20 | -0.40 | 0.22 | 0.12 | 0.11 | -0.13 | 0.28 | 0.03 | 0.75 | 1.00 |   |   |   |   |   |   |   |   |
|           | O | 0.17 | 0.09 | -0.32 | 0.41 | -0.09 | -0.29 | -0.08 | 0.02 | 0.27 | -0.26 | 0.55 | 0.12 | 0.74 | 0.83 | 1.00 |   |   |   |   |   |   |   |   |
|           | P | -0.04 | -0.06 | -0.05 | 0.02 | 0.73 | -0.58 | 0.48 | 0.33 | -0.47 | 0.38 | -0.10 | -0.06 | -0.22 | 0.41 | 0.17 | 1.00 |   |   |   |   |   |   |   |
|           | Q | 0.64 | -0.19 | -0.66 | 0.61 | -0.69 | 0.35 | -0.43 | -0.35 | 0.18 | -0.09 | 0.14 | 0.17 | 0.71 | 0.40 | 0.43 | -0.31 | 1.00 |   |   |   |   |

A, ethanol-toluene-soluble extractives; B, holocelulose; C, α-cellulose; D, hemicellulose; E, Klason lignin; F, acid soluble lignin; G, basic density (BD); H, ash content; I, volatile matter; J, fixed carbon content; K, calorific value; L, fuelwood value index; M, hydrolysis weight decrease; N, glucose content; O, xylose content; P, galactose content; Q, arabinose content. *, significant in 5% level; **, significant in 1% level.

Based on the Pearson correlation analysis, significant correlations between the α-cellulose and holocelulose content and between Klason lignin content and acid-soluble lignin content or basic density were found (Table 5). Those parameters, therefore, were eliminated from the AHP analysis [8]. Fixed carbon and FVI parameters in the assessment of biomass characteristics for firewood, as well as glucose, xylose, and arabinose content parameters in the assessment of biomass characteristics for liquid bio-fuel can also be eliminated due to the significant correlations with other parameters found (Table 4). Parameters used in the AHP analysis for biomass suitability as firewood feedstock in this study, therefore, were calorific value > ash content > volatile matter content > Klason lignin content > ethanol-toluene extract content > holocelulose content > α-cellulose content. Parameters used in the AHP analysis for biomass suitability as liquid bio-fuel feedstock in this research were hydrolysis weight decrease > α-cellulose content > Klason lignin content > holocelulose content > galactose content > ethanol-toluene extract content.

Table 6. Rank of species as firewood or liquid bio-fuel feedstock

| Species | For firewood | For liquid bio-fuel |
|---------|--------------|----------------------|
|         | Score | Rank | Score | Rank |
| C       | 132.7 | 6 | 66.8 | 7 |
| D       | 111.5 | 7 | 59.8 | 10 |
| Jp      | 163.8 | 3 | 65.5 | 8 |
| Ra      | 101.0 | 9 | 67.2 | 6 |
| G       | 84.4 | 11 | 69.1 | 4 |
| Wi      | 109.2 | 8 | 86.6 | 2 |
| M       | 169.2 | 2 | 91.1 | 1 |
| Gg      | 100.1 | 10 | 65.0 | 9 |
| J       | 137.6 | 4 | 78.0 | 3 |
| R       | 176.6 | 1 | 67.3 | 5 |
| S       | 135.0 | 5 | 56.8 | 11 |

Species codes refer to Table 1.
Table 6 shows the suitability of the species for firewood or liquid bio-fuel raw material on the basis of the scores and ranking of AHP analysis results. The consistency ratios of the AHP analysis for firewood and liquid bio-fuel were 9.42% and 9.50%, respectively. Scores for the AHP analysis results for firewood ranged from 84.4 to 176.6. Among all 11 species, Rambutan, Mango, and Java plum were ranked 1st to 3rd for firewood feedstock. On the other hand, the scores for liquid bio-fuel ranged from 56.8 to 91.1. Furthermore, Mango, White leadtree, and Jackfruit were ranked 1st to 3rd for liquid bio-fuel feedstock. Based on the results, Mango and Jackfruit are suitable as both firewood and liquid bio-fuel raw material. In contrast, some species, such as Rambutan, Strawberry tree, and Java plum are only suitable as firewood feedstock, suggesting that wood from those species should be used as energy resources with a heat conversion method. In addition, White leadtree and Guava are only suitable as liquid bio-fuel feedstock. Those species, therefore, should be used for energy resources with an enzymatic hydrolysis conversion method to produce reducing sugar for liquid bio-fuel production through fermentation processes. On the other hand, Durian and Gnetum showed a lower ranking for both firewood and liquid bio-fuel uses, suggesting that those species may be used for purposes other than bio-energy.

4. Conclusion

On the basis of the AHP analysis in this study, among all 11 species, Rambutan, Mango, and Java plum were the best three species for firewood feedstock, while Mango, White leadtree, and Jackfruit were the best three species for liquid bio-fuel feedstock. The branches of Durian and Gnetum may be used for purposes other than bio-energy. The parameters used to analyse the suitability of biomass as firewood were calorific value > ash content > volatile matter content > Klason lignin content > ethanol-toluene extract content > holocellulose content > α-cellulose content. Parameters for analysing the suitability of biomass as liquid bio-fuel feedstock in this study were hydrolysis weight decrease > α-cellulose content > Klason lignin content > holocellulose content > galactose content > ethanol-toluene extract content.

References
[1] Demirbas A. Combustion characteristics of different biomass fuels. Progress in Energy and Combustion Science 2004;30: 219–230.
[2] Klass DL. Biomass for Renewable Energy, Fuwl, and Chemicals. San Diego: Academic Press; 1998.
[3] Tobin CM. Wood for Fuel Calen. In: The Root of The Problem- What’s Driving Tropical Deforestation Today? Union of Concern Scientis; 2011. http://www.ucsusa.org/UCS_DriversofDeforestation_Chap8_Woodfuel.pdf.
[4] Telmo C, Lousada J. The explained variation by lignin and extractive contents on higher heating value of wood. Biomass and Bioenergy 2011; 35: 1663 – 1667.
[5] Öhgren K, Bura R, Saddler J, Zacchi G. Effect of hemicellulose and lignin removal on enzymatic hydrolysis of steam pretreated corn stover. Bioresource Technology 2007; 98: 2503-2510.
[6] Santos RB, Lee JM, Jameel H, Chang HM, Lucia LA. Effects of hardwood structural and chemical characteristics on enzymatic hydrolysis for biofuel production. Bioresource Technology 2012; 110: 232-238.
[7] Ramosa MA, de Medeirosa PM, de Almeidaa ALS, Felicianob ALP, de Albuquerque UP. Can wood quality justify local preferences for firewood in an area of caatinga (dryland) vegetation? Biomass and Bioenergy 2008; 32: 503 – 509.
[8] Schmoldt D, Kangas J, Mendoza G, Pesonen M. The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making, Vol. 3 in the series Managing Forest Ecosystems, Dordrecht, Boston, London: Kluwer Academic Publishers. 2001.
[9] Saaty TL, Decision making with the analytic hierarchy process. Int. J. Services Sciences 2008;1: 83-98.
[10] Myllyvita T, Leskinen P, Lahtinen K, Pasanen K, Sironen S, Kahkonen T, Sikanen L.
Sustainability assessment of wood-based bioenergy - a methodological framework and a case-study. Biomass and Bioenergy 2013; 59: 293 – 299.

[11] Irawati D, Yokota S, Niwa T, Takashima Y, Ueda C, Ishiguri F, Mizuka K, Yoshizawa N. Enzymatic saccharification of spent wood-meal media made of 5 different tree species after cultivation of edible mushroom Auricularia polytricha. Journal of Wood Science. 2012;58:180-183.

[12] Anonymous. Annual Book of ASTM Standards. D-1102 s.d 1110 Standard Method of Wood Chemistry. Philadelphia. USA; 1984.

[13] Marsoem SN, Irawati D. Basic properties of Acacia mangium and Acacia auriculiformis as a heating fuel. AIP Conf. Proc. 2016; 1755: 130007.

[14] Kumar R, Pandey KK, Chandrashekar N, Mohan S. Study of age and height wise variability on calorific value and other fuel properties of Eucalyptus hybrid, Acacia auriculiformis and Casuarina equisetifolia. Biomass and Bioenergy 2011; 35: 1339 – 1344.

[15] Chettri N, Sharma E. Scientific assessment of traditional knowledge on firewood and fodder values in Sikkim, India. Forest Ecology and Management 2009; 257: 2073–2078.

[16] Irawati D, Takashima Y, Ueda C, Sutapa JPG, Marsoem SN, Ishiguri F, Mizuka K, Yoshizawa N, Yokota S. Ozone treatment of spent medium from Auricularia polytricha cultivation for enzymatic saccharification and subsequent ethanol production. Journal of Wood Science. 2013; 59:522–527.

[17] Rowell RM, Pettersen R, Han JS, Rowell JS, Tshabalala MA. Cell Wall Chemistry. In: Rowell RM, editor. Handbook of wood chemistry and wood composites, Boca Raton: CRC Press; 2005, p.35-74.

[18] Fengel D, Wegener G. Wood: Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin, New York. 1984.

[19] Nawawi DS, Wicaksono SH, Rahayu IS. Kadar Zat Ekstraktif dan Susut Kayu Nangka (Arthocarpus heterophyllus) dan Mangium (Acacia mangium). J. Ilmu dan Teknologi Kayu Tropis 2013; 11: 46-54. In Indonesian.

[20] Lukmandaru G, Vembrianto K, Gazidy AA. Aktivitas Antioksidan Ekstrak Metanol Kayu Mangifera indica L., Mangifera foetida Lour, dan Mangifera odorata Griff. J. Ilmu Kehutanan 2012; 6:18-29. In Indonesian.

[21] Eaton RA, Hale MDC. Wood: Decay, Pests and Protection. Chapman and Hall. London. 1993.

[22] Sjostrom E, Westermark U. Chemical Composition of Wood and Pulps: Basic Constituents and Their Distribution. In: Sjostrom E, Alen R, editors. Analytical Methods in Wood Chemistry, Pulping, and Papermaking, New York: Springer-Verlag; 1999, p.1-8.

[23] Goldstein IS. Organic Chemical from Biomass. Boca Raton: CRC Press Inc.1981.

[24] Dence CW, The Determination of Lignin. In: Lin SY, Dance CW, editors. Methods in Lignin Chemistry, Berlin: Springer-Verlag; 1992, p.33-57.

[25] Yazdani MG, Hamizan M, Shukur MN. Investigation of the fuel value and the environmental impact of selected wood samples gathered from Brunei Darussalam. Renewable and Sustainable Energy Reviews 2012; 16: 4965–4969.

[26] Hakki1a P, Parikka M, Fuel Resources from The Forest. In: Richardson J, Bjorheden R, Hakki1a P, Lowe AT, Smith CT, editors. Bioenergy from Sustainable Forestry: Guiding Principles and Practice, Dordrecht: Kluwer Academic Publishers; 2002.

[27] Montes CS, da Silva DA, Garcia RA, de Mun“ iz Gib, Weber JC. Calorific value of Prosopis africana and Balanites aegyptiaca wood: Relationships with tree growth, wood density and rainfall gradients in the West African Sahel. Biomass and Bioenergy 2011; 35: 346 – 353.

[28] Martawijaya A, Kartasujana I, Kadir K, Prawira SA. Atlas Kayu Indonesia. Vol1-3. Departemen Kehutanan. Badan Penelitian dan Pengembangan Kehutanan. Bogor. 2005. In Indonesian

[29] Yantasath K, Anusontpornperm S, Utistham T, Soontornrangson W, Watanatham S. Acacia for Fuelwood and Charcoal. Acacia for Rural, Industrial, and Environmental Development. Proceeding Of The Second Meeting of the Consultative Group For Research and Development
Of Acacia (COGREDA), Editor K. Awang, dan D. A. Taylor. Udorn Thani. 1993. p.144-150.

Dombro DB. Eucalyptus pellita: Amazonia Reforestation’s Red Mahogany. Palneta Verde Reforestacion S.A. Colombia. 2010. http://www.myreforestation.com/downloads/Eucalyptus_pellita_2010_e-book.pdf.

Acknowledgement
Part of this research was financially supported by the Education Development Program of the Faculty of Forestry, Gadjah Mada University.