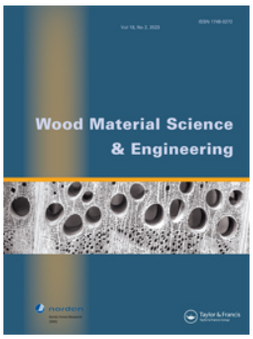

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ORIGINAL ARTICLE

Investigation of the chemical profiles of seven wood species for their potential applications

Mohammad Jakir Hossain[a], Rupak Kumar Ghosh[a], Atanu Kumar Das [b], Shambhu Chandra Nath[a], Md. Rakibul Islam[a], Shaheen Akhter[a] and Md. Saidur Rahman[a]

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ABSTRACT

Determination of the chemical composition of biomaterial is important for their valued utilization in biorefinery. In this study, the chemical composition of seven wood species, i.e. lambu (*Khaya anthotheca*), raj-koroi (*Albizia richardiana*), jhau (*Casuarina equisetifolia*), sil-koroi (*Albizia procera*), katbadam (*Terminalia catappa)*, jolpai (*Elaeocarpus robustus*), and arjun (*Terminalia arjuna)* were examined. The chemical characterization of these wood species can expedite a further study on the extraction of cellulose, lignin, and extractive. α-cellulose content was in the range of 37.0% to 42.1% and lignin content was 20.4% to 34.1%. The solubility in 1% caustic soda was 16.1% to 24.3%. The α-cellulose and lignin content were similar to other wood species. Therefore, these species can be a potential source of raw material for biorefinery.

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Wood; chemical characterization; potential application

1. Introduction

Wood is a hygroscopic material mainly composed of a complex matrix of tree biopolymers. It is heterogeneously aggregated of cell wall fibers composed primarily of cellulose and hemicellulose, joined by major cell wall constituent polymers of lignin. Cellulose is the major component in the walls of plant cells, helping the plant to remain stiff and upright. Holocellulose is the total polysaccharide fraction of wood that is composed of cellulose and all of the hemicelluloses. Hemicellulose is branched, and it is composed of several different kinds of hexose and pentose sugar monomers (Wiedenhoeft 2010). Lignin is often called the cementing agent that binds individual cells together (Boerjan *et al*. 2003, Wiedenhoeft 2010). Extractives include resigns, fats, oils, gum, starch, waxes, tannins, and coloring materials. These components contribute to various wood properties, including odor, color, taste, hygroscopicity, density, and decay resistance (Wiedenhoeft 2010).

Wood is one of the prime sources of feedstock for the production of pulp and paper, boards, and furniture, and increasingly popular bio-refinery products (biochemicals, biomaterials, biofuels, and others). The currently growing market demand for naturally derived compounds and the need to replace synthetic ones have led to the increasingly efficient utilization of wood (reuse, recycling, recovery), as well as increasing interest in studying the individual chemical components of wood and identifying novel application pathways and value-added solutions for particular bioactive molecules (Royer *et al*. 2012, Routa *et al*. 2017). The amount of chemical constituents, i.e. cellulose and lignin, is an important factor for considering its suitability as a raw material for bio-refinery and selecting the optimum conversion method.

Therefore, knowledge of the chemical composition of wood is inevitable for its better utilization. It is important to expand knowledge of the chemical constituents of this wood so that the region's timber resources will have greater potential and utility in the technological and industrial process such as the production of pulp and paper, tannins, and as natural wood preservatives (Hillis 1971, Argyropoulos 2001, Das *et al*. 2015, 2016). On the other hand, the alternative wood species need to be examined for reducing the raw material shortage issue for wood-based industries. There are seven wood species, i.e. *Khaya* anthotheca*, Albizia richardiana, Casuarina equisetifolia, Albizia procera, Terminalia catappa, Elaeocarpus robustus, and Terminalia arjuna*, which chemical composition haven't been studied. *K. anthotheca* can grow in deep fertile moist soils and it can be 60 m in height (Alam *et al*. 2012). Similarly, *A. procera* (Troup, 1921), *E. robustus* (Zmarzty, 2001), and *T. arjuna* (Kumar and Maulik, 2013) prefer moist soils but they can grow at a different height. The maximum height of *A. procera* (Troup, 1921), *E. robustus* (Zmarzty, 2001), and *T. arjuna* (Kumar and Maulik, 2013) is 25, 20, and 20–30 m, respectively. On the other hand, *A. richardiana* can grow in dry to moderately moist soil and it can be 30–40 m tall (Rahman *et al*. 2013). However, *T. catappa* can grow in dry

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

to moist soils and saline soils. It can attain a maximum height of 35 m (Göltenboth *et al*. 2006). The habitat of *C. equisetifolia* is different from the other six species. It prefers a hot sub-humid area to grow and can be 10–40 m in height (Göltenboth *et al*. 2006). The study on the chemical profiles of these can provide a better understanding of their utilizations.

That's why this study has been conducted to analyse the chemical components of seven wood species. Cellulose, lignin, and extractive content were determined. Cold water, hot water, and caustic soda (NaOH) solubility of each species were also studied.

2. Material and methods

2.1. Raw materials

A 20–30 years old and defect-free seven timber species, i.e. Khaya anthotheca, Albizia richardiana, Casuarina equisetifolia, Albizia procera, Terminalia catappa, Elaeocarpus robustus, and Terminalia arjuna, were selected in this study. There were three trees of each species were collected for the analysis of chemical composition.

Reagent grade (≥95% purity) sodium hydroxide (NaOH), acetic acid (CH_3COOH), Sodium chlorite ($NaClO_2$), and sulfuric acid (H_2SO_4) were received from Carolina Biological Supply Company, New York City, USA. Analytical grade (≥95% purity) benzene and ethanol were sourced from Merck KGA, Darmstadt, Germany.

2.2. Preparation of raw material

The trees were cut at 15–25 cm above ground level and then subdivided equally into the top, middle and basal portions according to their total length. Each part was debarked and converted into boards. The boards were chipped using an electric planning machine. The chips were dried in the sun and the dried chips were then milled by a Wiley mill to get wood powder. The powder of three portions was mixed thoroughly to obtain a representative sample of a whole tree. The powders were then sieved to obtain a 40–60 mesh. This procedure was applied for all seven species used in this study. The powders were stored in an airtight container for further analysis.

2.2. Chemical analysis

Chemical analysis of seven timber species was conducted based on TAPPI standards. To determine the cellulose content of seven wood species, holocellulose and α-cellulose were analysed by following the standard of T 249-75 and T 203 cm-99, respectively. Lignin content was analysed based on the T-222 cm-02 standard. Extractive content was determined following the T-204 cm-97 standard. The polymer degradation was investigated by the analysis of solubility. T-207 cm-99 standard was used to anlayse cold and hot water solubility and alkaline solubility was determined by T-212 om-02 standard. The carried out analyses are described in this section.

2.2.1. Holocellulose

A 2 g extractive-free sample, 160 ml of distilled water, 0.2 ml of cold CH_3COOH, and one gram of $NaClO_2$ were placed in a 250 ml flask. It was then kept in a water bath at 70–80°C for 5 h. One gram of $NaClO_2$ and 0.2 ml of cold CH_3COOH were added to the mixture with continuous stirring in a 1 h interval. At the end of five hours, the flask was placed in an ice-water bath and filtered into a known weight of coarse porosity fritted-glass crucible. The residue was washed with acetone followed by ethanol. The crucible containing residue was then oven-dried at 105°C and weighed until a constant weight was reached. The following equation was used to calculate the holocellulose content.

$$\text{Holocellulose content}(\%) = (W_3 - W_4)/(100 \times W_2) \times (100 - W_1)$$

where W_1 is alcohol-toluene extractive content (percent), W_2, W_3, and W_4 were weight (dry mass) of samples, residue and crucible, and crucible, respectively.

2.2.2. α-cellulose

A 3 g of oven-dried holocellulose sample was placed in a 250 mL Erlenmeyer flask and it was then put in a water bath maintaining a temperature of 20°C. Then, 50 ml of 17.5% NaOH solution was poured into the flask and mixed thoroughly for one minute. After that, the reaction between the sample and solution was continued for 29 min followed by adding 50 ml of distilled water and mixing for another minute. The mixture was kept for another 5 min to complete the reaction and it was filtered using a known weight of fritted-glass crucible by the aid of vacuum suction. The residue was washed with 50 ml of 8.3% NaOH followed by 40 ml of 10% CH_3COOH, and 1000 ml of hot distilled water. The crucible was oven-dried in an oven at 103 ± 2°C until obtaining a constant weight. α-cellulose was calculated using the following formula.

$$\alpha\text{-cellulose}(\%) = (W_3 - W_4)/(100 \times W_2) \times W_1$$

where W_1 is holocellulose content (percent), W_2, W_3, and W_4 were weight (dry mass) of holocellulose sample, residue and crucible, and crucible, respectively.

2.2.3. Lignin

A 2 g of extractive free sample and 40.0 ml of 72% H_2SO_4 were kept in a beaker followed by continuous stirring with a glass rod until the complete dispersion of the sample. It was then transferred to the flask and 1540 ml of hot water was added to the mixture. The mixture was boiled for 4 h, maintaining constant volume by the addition of hot water frequently. After that, it was kept overnight. Then, it was filtered using a known weight of fritted-glass crucible by the aid of vacuum suction and washed with hot water to remove the residual acid from the lignin. The crucible containing the residue was oven-dried at 103 ± 2°C until obtaining a constant weight. Lignin content was calculated using the following equation.

$$\text{Klason lignin content}(\%) = [(W_2 - W_3)/W_1] \times 100$$

where W_1, W_2, and W_3 were weight (dry mass) of sample, residue and crucible, and crucible, respectively.

2.2.4. Extractive

A 5 g sample was used for extractive analysis. The solvent was a mixture of benzene and ethanol in the ratio of 2:1 and kept in a flask. Soxhlet apparatus was used to extract extractive for a period of 4–5 h. The solvent was evaporated and the flask was dried at 105 ± 3°C for 1 h followed by cooling in a desiccator and weighing. The extractive content was measured using the following equation.

$$\text{Extractive content}(\%) = [(W_e - W_b)/W_p] \times 100$$

where W_e, W_p, and W_b are weight (dry mass) of flask with extractive, wood powder and flask, respectively.

2.2.5. Cold water solubility

A 2 g sample was placed in a 500 ml beaker, and 300 ml of distilled water was added to the beaker. After wetting the sample, extraction was carried out with constant stirring at room temperature (23°C) for 48 h. The mixture was then transferred to a tared filtering crucible and washed with 200 ml of cold distilled water. After that, it was dried at 105°C to a constant weight. The following equation was used to calculate the cold water solubility.

$$\text{Cold water solubility}(\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the test specimen, respectively.

2.2.6. Hot water solubility

A 2 g sample and 100 ml of hot distilled water were put in a 250 ml conical flask. The mixture was placed in a boiling water bath and digested by the reflux condenser for 3 h. Then, the mixture was transferred to a tared filtering crucible and washed with 200 ml of hot distilled water. It was dried at 105°C until reaching constant weight. The calculation of hot water solubility was done using the following equation.

$$\text{Hot water solubility}(\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the sample, respectively.

2.2.7. Alkaline solubility

A 2 g sample and 100 ml of 1% NaOH solution were kept in a 500 ml conical flask. The mixture was stirred with a glass rod, and it was then placed in a water bath at 97–100°C for 60 min. After that, it was transferred to a tared filtering crucible and washed with 100 ml of hot water. It was then soaked in 25 ml of 10% CH_3COOH for 1 min followed by soaking in 15 ml of 10% CH_3COOH for 1 min. Finally, it was washed with hot water until the removal of the remaining acid. Alkaline solubility was calculated using the following equation.

$$\text{Alkaline solubility}(\%) = [(A - B)/A] \times 100$$

where A and B are before and after extraction weight (dry mass) of the sample, respectively.

3. Results and discussion

3.1. Cellulose

Holocellulose and α-cellulose content of seven wood species are presented in Figure 1. The holocellulose and α-cellulose content of seven species were in the range of 62.1% to 72.6% and 37.0% to 42.1%, respectively. *A. richardiana* showed the highest amount of holocellulose (72.6%) and α-cellulose (42.1%) than *K. anthocera*, *C. equisetifolia*, *A. procera*, *T. catappa*, *E. Robustus*, and *T. arjuna*. The α-cellulose content of *Eucalyptus* spp. (Pereira *et al*. 2013), *Acacia mangium* (Pinto *et al*. 2005), and *Populus* spp (Kacik *et al*. 2012) were 46.1% to 48.8%, 46.5%, and 43.1% to 45.9%, respectively in previous studies. The holocellulose content of *Acacia mangium* (Pinto *et al*. 2005) and *Populus* spp (Kacik *et al*. 2012) were 70.9% and 81.7% to 82.9%, respectively. In comparison to other wood species, seven wood species used in this study showed more or less similar content of α-cellulose and holocellulose contents.

3.2. Lignin

The measured lignin content of seven wood species has been shown in Figure 2. The observed lignin content of seven wood species was 20.4% to 34.1% and it was significantly different from each other. The lowest lignin content (20.4%) was observed for *A. richardiana* and it was the highest (34.1%) for *K. anthocera*. In previous studies, the lignin content of *Eucalyptus* spp. (Pereira *et al*. 2013), *Acacia mangium* (Pinto *et al*. 2005), and *Populus* spp (Kacik *et al*. 2012) were 28.8% to 31.4%, 27.1%, and 17.7% to 23.7%, respectively. The lignin content of seven wood species was comparatively similar to other wood species observed in previous investigations.

The variability of the lignin content within these species could indicate better possible end-uses, with *K. anthotheca, T. catappa, E. robustus, and T. arjuna* showing high contents that could be exploited for energy purposes (biocoal production) or aiming at this rich polyphenolic pool, while *A. richardiana*, with low lignin content, appears to be more suited for pulp or polysaccharides production (maybe even ethanol).

3.3. Solubility

Figure 3 represents the solubility of seven wood species. The range of cold water, hot water, and 1% caustic soda (NaOH) solubility were 1.0% to 5.7%, 0.9% to 8.8%, and 16.1% to 24.3%, respectively. The highest hot water (8.8%) and NaOH solubility (24.3%) was found for *A. procera* while *T. arjuna* showed the highest solubility (5.7%) in cold water. Again, the lowest cold water (1.0%) and NaOH (16.1%) solubility were observed for *C. equisetifolia*. Meanwhile, *E. Robustus* showed the lowest (0.9%) hot water solubility. On the other hand, all species were more soluble in NaOH solution comparison to in cold and hot water. Cellulose is more resistant but hemicellulose is prone to degrade by the presence of NaOH (Horvath 2006) which may cause the higher solubility

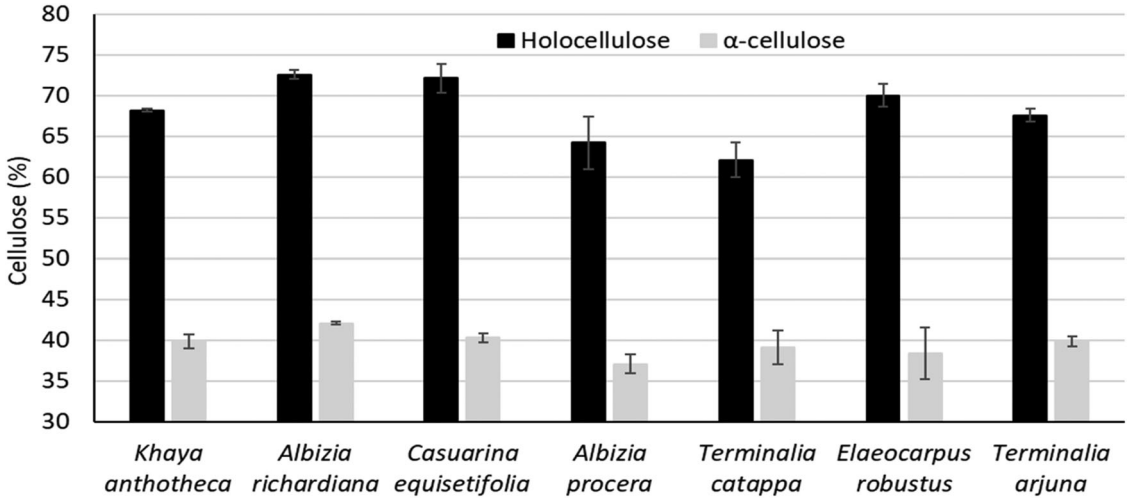

Figure 1. Cellulose content of seven wood species.

in 1% NaOH solution. The cold water solubility of *Cedrus libani* and *Cedrus penhallowii* was 0.8% and 3.3%, respectively (Horvath 2006). Again, the water solubility of *Pinusbrutia*, *Pinusnigra*, *Fagus orientalis*, and *Fagussy lvatica* was 1.5%, 4.2%, 2.3%, and 3.4%, respectively (Horvath 2006). The findings of water solubility for seven wood species were in

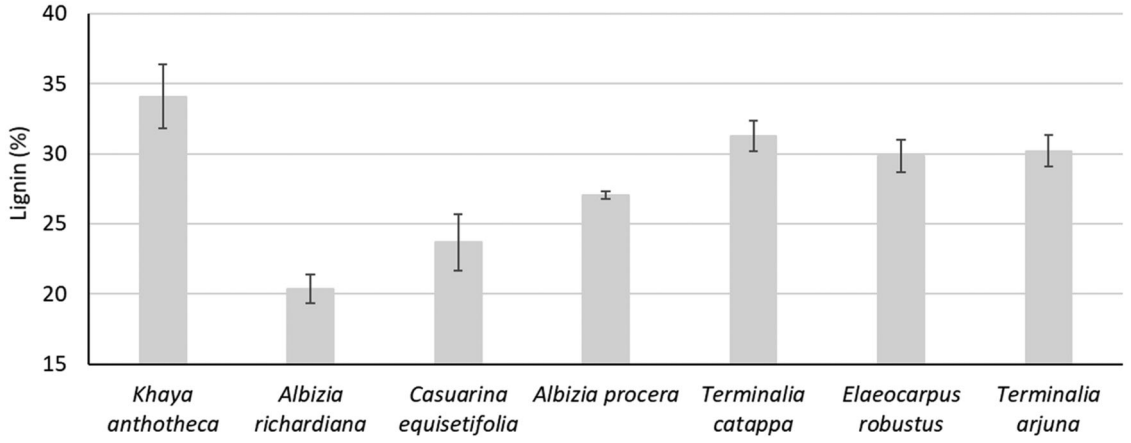

Figure 2. Lignin content of seven wood species.

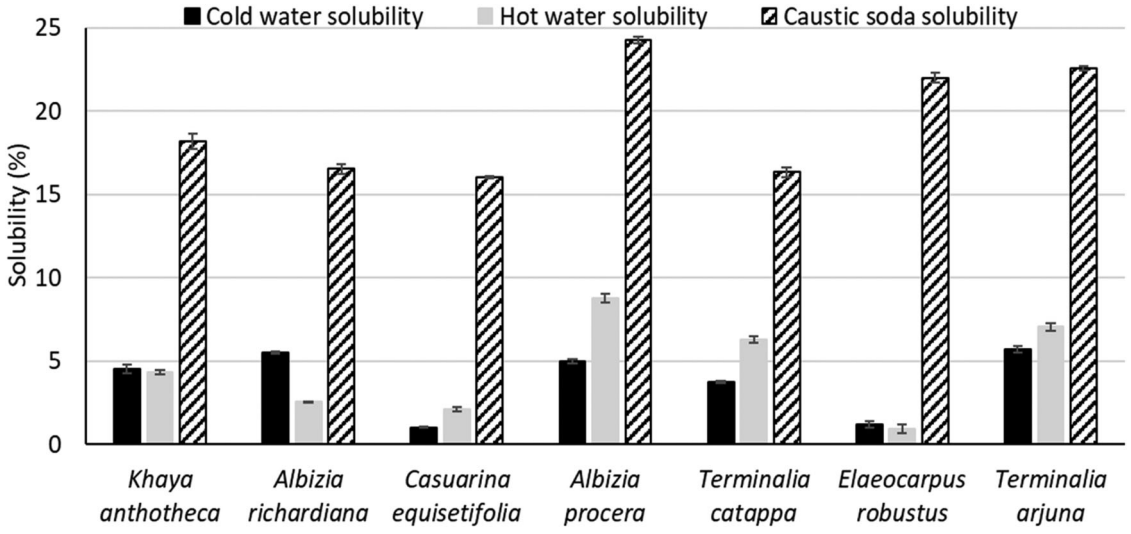

Figure 3. Solubility of seven wood species.

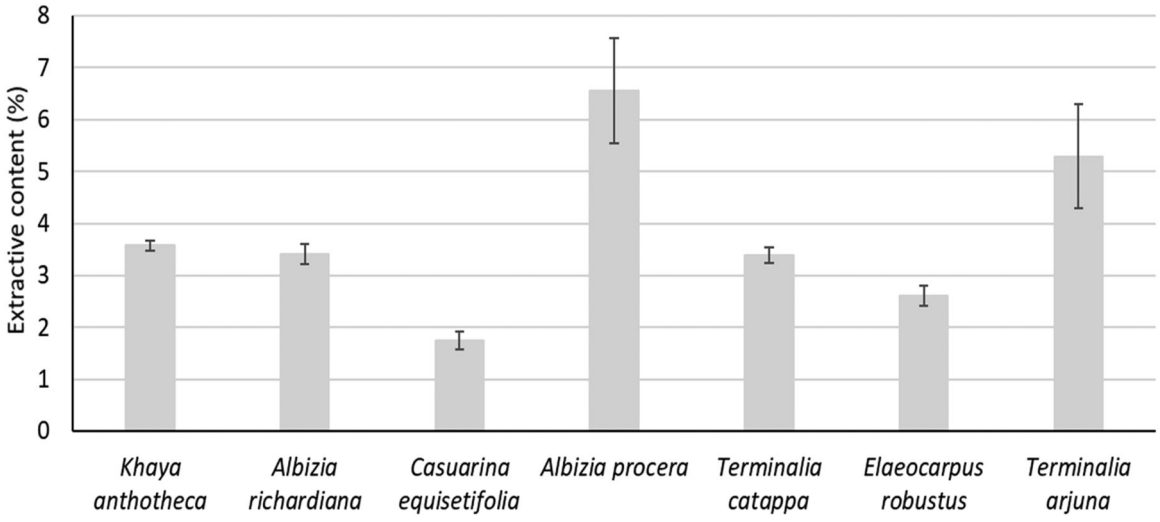

Figure 4. Extractive content of seven wood species.

the range of previous studies. According to the results, the polysaccharides of *A. procera* and *T. arjuna* are easier to degrade, which indicates that these can consume less chemical during bioconversion, i.e. pulping. This may provide the idea for selecting the parameters, i.e. chemical charge, time, and temperature, during the conversion process.

3.4. Extractive

The benzene-ethanol extractive content of seven wood species is shown in Figure 4 and it was in the range of 1.7% to 6.6%. The highest extractive content (6.6%) was found for *A. procera*, and it was the lowest (1.7%) for *C. equisetifolia*. The extractive content of *Eucalyptus* spp. (Pereira *et al*. 2013) and *Populus* spp (Kacik *et al*. 2012) was 3.1% to 5.0% and 1.7% to 3.8%, respectively. On the other hand ethanol-toluene, dichloromethane, and methanol-water extractive of *A. mangium* were 4.5%, 1.3%, and 4.1%, respectively (Pinto *et al*. 2005). The extractive content of seven wood species of this study was in the range of other wood species except for *A. procera* and *T. arjuna*.

4. Potential applications

Cellulose and lignin are the most valuable resources for developing value-added products. Extraction of extractive can contribute to employ in advanced applications, i.e. biomedical and biochemical. The significant content of cellulose and lignin of seven species compared to other wood species can appeal to consider them as an alternative source of cellulose and lignin. These have the potential for application in bioenergy generation, biochemical production, and biomedical applications. However, based on the chemical analysis, *A. richardiana* and *C. equisetifolia* can be targeted for their polysaccharides content while *K. anthotheca*, *T. catappa*, *E. serratus*, and *T. arjuna* can be focused on for their lignin content. In addition, the extractive content of *A. Procera* and *T. arjuna* can be considered for possible applications in biochemical extraction and biomedical.

5. Conclusions and recommendations

The chemical composition of seven wood species was investigated in this study. Cellulose and lignin content was more or less close to other wood species used for commercial purposes. *K. anthotheca, T. catappa, E. robustus, and T. arjuna* had high lignin contents while *A. richardiana and C. equisetifolia* showed high cellulose content. The high extractive content was observed in *A. Procera* and *T. arjuna*. The solubility analysis showed that *A. procera* and *T. arjuna* can be easier to apply in bioconversion. Therefore, these seven wood species indicate the potential source of raw material for developing value-added products. Further studies are needed to develop a suitable extraction method of cellulose, lignin, and extractive for these new raw materials.

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Data availability

Not applicable.

Ethical approval

Not required.

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