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Chemical Composition of *Yushania alpina* (K. Schum.) W.C.Lin (1974) (Highland Bamboo) Grown in Ethiopia

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ABSTRACT

Chemical properties of any lignocellulose species are one of the major properties that used to select the material for any purpose either chemical or biological. Since bamboo is one of the woody grass species used for various applications worldwide; therefore knowing the chemical composition plays greater a role. Based on the above assumption, this research was conducted to study the major chemical composition of *Yushania alpina* (K. Schum.) W.C.Lin (1974) (Highland Bamboo) grown around Enjibara in Ethiopia. In the work, *Yushania alpina* (Highland Bamboo) sample was harvested, dried, milled using a Wiley Mill, sieved and all chemical composition were determined based on the National Renewable Energy Laboratory (ASTM) approaches, except that the Kurschner-Hoffer method (1931) was applied for cellulose determination. Based on the study, the chemical composition characterization shows that *Yushania alpina* has 46.76% cellulose content, 25.27% lignin content, 12.18% hemicellulose, 3.77% ash, 12.23% hot-water extractive and 3.93% ethanol-toluene extractives.

Keywords**:** *Yushania alpina,* Chemical composition, Cellulose, Hemicellulose, Lignin

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1. INTRODUCTION

Bamboos belong to the family of grasses (*Poaceae*), just like sugar cane and other perennial crops. Woody bamboos are especially known for their high versatility, with many current and potential uses. Bamboo has a wide distribution, naturally occurring in a range between 40 degrees southern and northern latitude on all continents, except Europe. Though bamboos occur in both tropical and temperate climates, warm and humid conditions are preferred by most species. Bamboo adapts easily to a range of climatic and soil conditions, and is therefore widely distributed in the tropical and subtropical zones between approximately 46°N and 47°S latitude, covering a total area of about 31.5 million ha, and accounted for about 0.8% of the world's total forested area in 2010 (Song *et al*., 2011).

Globally, Asia has the richest bamboo resources, accounting for 65% of all global bamboo resources. The major bamboo producing countries include India, China, and Indonesia in consecutive order (Wang *et al.*, 2014). Sub-Saharan Africa is home to approximately 3 million hectares of bamboo forest, primarily *Yushania alpina* (synonyms *Arundinaria alpina*) (a highland bamboo) and *Oxytenanthera abyssinica* (a lowland bamboo) growing on arid or very poor soils. Ethiopia is home to the largest area of natural bamboo in Africa. Ethiopia as a whole has about 1 million hectares of bamboo, from which 850,000 hectares are lowland and 350,000 hectares are highland bamboo (Kassahun *et al.*, 2000). Ethiopia is also committed to restoring a sixth of its land into productivity by 2025, with bamboo playing a key role in the effort.

Bamboo plays an important role in building a sustainable future, whether it be carbon sequestration, erosion control, or livelihood development. Bamboo has a lot of advantages such as that it is a superior wood substitute, it is cheap, efficient, and fast-growing, it has a high potential for environmental protection, it has wide ecological adaptation, and the state of natural forest is shrinking globally (Zenebe *et al*., 2014). Bamboo has been used in over 1500 applications and the numbers are growing rapidly. For example, bamboo is used in construction, flooring, paper and furniture, as fabricated panels, handicrafts, curtains, modern ceilings, bio-energy, charcoal, clothing, medicine, food (edible bamboo shoots), beverage (bamboo beer, bamboo soft drinks, etc.). The last are important bamboo products especially in China (Scurlocka *et al*., 2000 and Zenebe *et al*., 2014).

Bamboo is a fast-growing and short rotation crop and is widely distributed around the world. Bamboo matures in a short time (3–5 years) compared to f softwoods and hardwoods (Krzesinska *et al.*, 2009) and it contains a large amount of holocellulose. Therefore, bamboo has been considered as a potential feedstock for bioethanol production in recent years due to features such as its high holocellulosic content, rapid growth, perennial nature, tolerance to extreme climatic conditions, and low management requirements.

The lignocellulose matrix is the primary building block of plant cell walls. It is a very heterogeneous natural material. Plant biomass is mainly composed of cellulose, hemicellulose, and lignin, along with smaller amounts of pectin, protein, extractives (soluble nonstructural materials such as nonstructural sugars, nitrogenous material, chlorophyll, and waxes) and ash. The composition of these constituents is not uniform and varies from one plant species to another. The ratios between various constituents within a single plant also vary with age, stage of growth and other conditions (Kumar *et al*., 2009 and Isikgor & Becer, 2015). The major gross difference in the composition can be due to variation among species, genetic factors and ecological conditions of growth. Approximately 75% of all by lignocellulose is comprised of polysaccharides, which can potentially be converted into monosaccharides for fermentation.

Table 1. The chemical composition in different biomass cell walls (Marriot *et al.*, 2016).

Biomass	Dicots (%)	Grasses (%)	Softwoods (%)	Hardwood (%)
Cellulose	45-50	35-45	40-45	40-55
Hemicellulose	20-30	40-50	20-30	20-35
Lignin	7-10	20	25-35	18-25

Lignin is the three-dimensional, amorphous phenylpropane based polymer that glues the fibers together in the middle lamella and the fibrils together in the secondary cell wall. Lignin gives the tree and the wood its unique mechanical strength. It gives strength and rigidity to plant cells and protects the plant from diseases and microorganisms (Isikgor & Becer, 2015). The building blocks of lignin, the phenylpropane units, are randomly linked to each other by ether and carbon-to-carbon bonds. The phenylpropane units are of *p*-coumaryl, coniferyl, and sinapyl alcohol. Different plant types produce these phenylpropane units in different ratios. For example, hardwood contains more sinapyl alcohol, grasses generate more *p*-coumaryl alcohol, while coniferyl alcohol dominates in softwoods (Adler *et al.*, 1977).

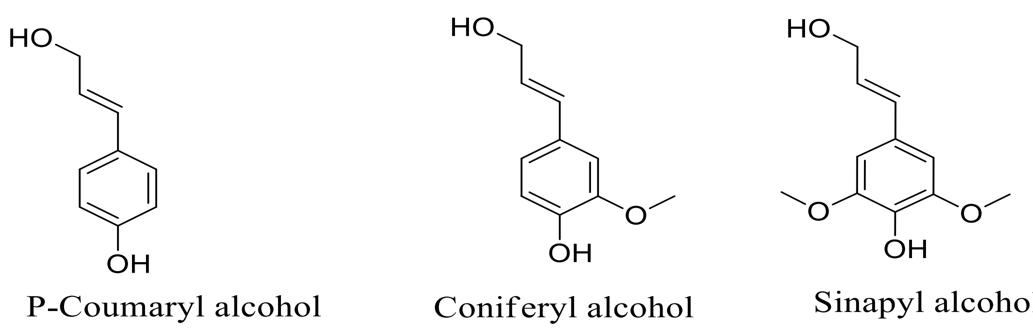

Figure 1. A structural segment of softwood lignin (Adler *et al.*, 1977).

Cellulose is the main constituent of lignocellulose and woody material and is located predominantly in the secondary cell wall. In most wood species, 40 – 45% of the dry substance is cellulose. Cellulose is a homopolysaccharide composed of *β*-D-glucopyranose units linked together by (*β*-1-4)-glycosidic bonds which are more stable than hemicellulose glycosidic bonds (Kumar *et al*., 2009). The β configuration orients the glucose molecules in such a way that each polymer forms hydrogen bonds with the adjacent ones and coalesces into very strong, long and straight microfibrils. Due to intramolecular and intermolecular hydrogen bonding within the cellulose structure, cellulose can form very tightly packed crystallites. It is believed that native wood cellulose molecules in the secondary wall consist of about 10,000 glucose units, and are monodispersed. On the other hand, the native cellulose molecules in the primary cell wall are polydispersed and have a lower average molar mass. This regularly ordered structure can sometimes be so tight that no enzyme or water can penetrate it. However, cellulose fibers in nature are not purely crystalline and have amorphous regions, which make the fibers at least partially hydrated. This characteristic of the natural cellulose enables enzymes access to the substrate during hydrolysis (Wyman *et al.*, 2005).

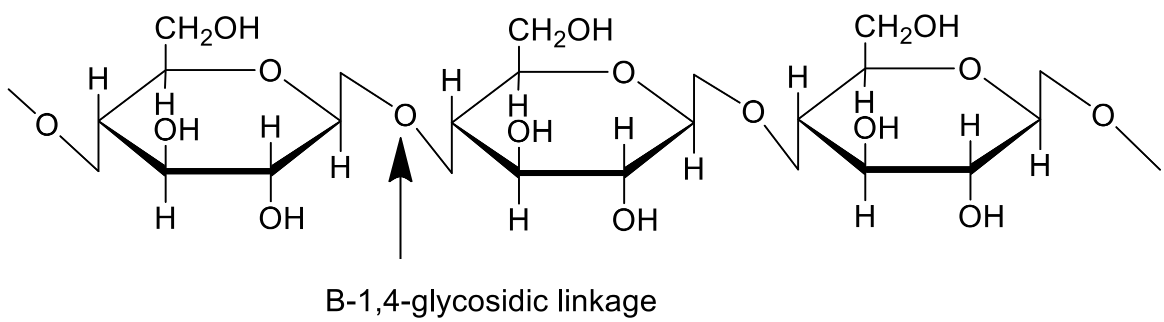

Figure 2. Structure of cellulose.

Hemicellulose is also a plant polysaccharide and comprises 20-35% of the biomass of most plants. Unlike cellulose, hemicellulose is not chemically homogeneous, rather it is composed of polymers of pentoses (xylose, arabinose), hexoses (mannose, glucose, galactose) and sugar acids. Hemicelluloses differ in composition too; hardwood hemicelluloses contain mostly Xylan, while glucomannan is the main constituent of softwood hemicelluloses (Isikgor & Becer, 2015). Due to their amorphous morphology, hemicelluloses can be hydrolyzed easily by chemical and enzymatic treatments (Wyman *et al.*, 2005).

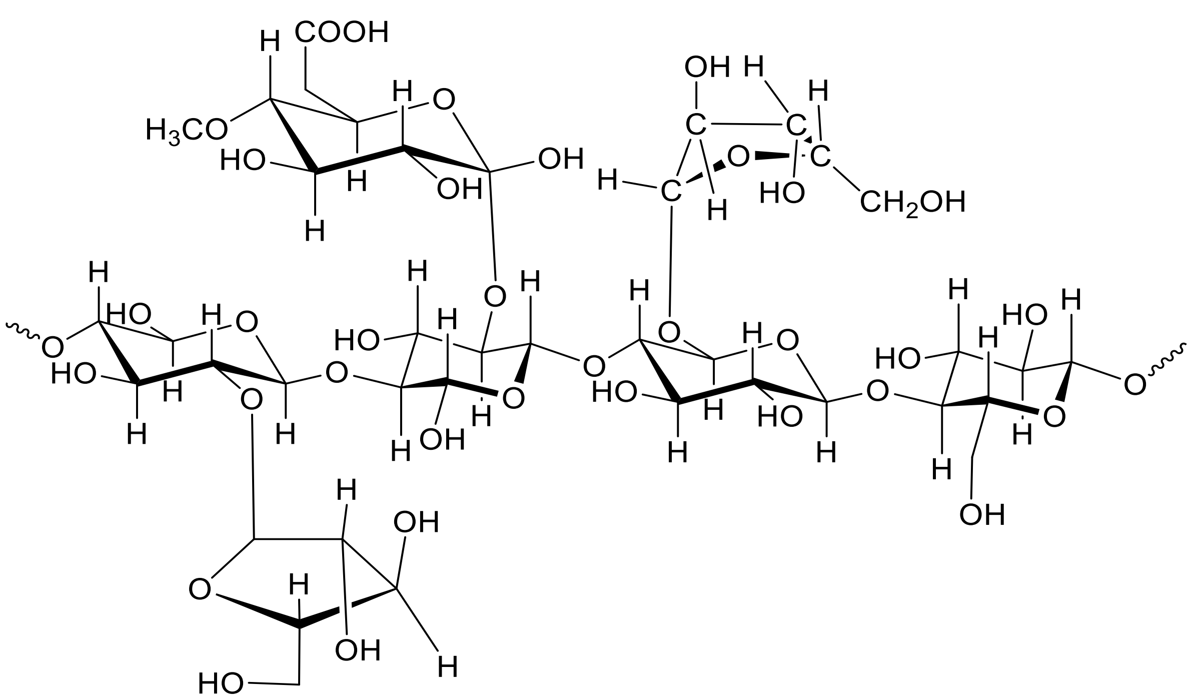

Figure 3. Structure of hemicellulose.

Extraneous components are not considered as essential structural parts of the wood. The extraneous components include the substances that are soluble in neutral organic solvents and cold water or are volatile with steam and are called the extractives. In the wood of the temperate zone, the extractives soluble in organic solvents are consistently higher in softwood. They consist of a wide range of low-molecular-mass substances (Fengel *et al.*, 1984) such as resin, fats, phenols and carbohydrates. Some extractives are energy sources for the wood cells and take part in the catalysis of biosynthetic processes. Extractives can also protect the wood against microbiological damage or attack by herbivores. The content of extractives in wood is typically 3 – 5%, but the content can vary in different wood species, parts of the wood, and even at seasons. Therefore, this study was conducted to determine the chemical composition of *Yushania alpina* (Highland Bamboo) grown in Enjibara, Ethiopia.

2. MATERIAL AND METHODS

2. 1. Sample collection and preparation

Bamboo stems from 3 years old *Yushania alpina* was harvested from Enjibara. The harvested bamboo culm was allowed to dry in the open air for a week. The dry bamboo culm was cut into a small size suitable for further milling processes and dried in the oven for 24 h. at 50 °C. Subsequently, it was placed in a hammer mill and Willey mill to reduce it to appropriate size. The milled bamboo sample was sieved to 250 μm particle sizes. The prepared sample was sealed into plastic bags and labeled with appropriate codes for further chemical analysis.

2. 2. Characterization of *Yushania alpina* chemical composition

The chemical composition of *Yushania alpina* was determined by using the following methods. All the chemical composition (ash, moisture hot water-soluble, ethanol-toluene extractive, Klasson-lignin, and hemicellulose content) were determined by the standards of the American Society for Testing Materials (ASTM), except that the Kurschner-Hoffer method was applied for cellulose determination. The experiment was performed in triplicate and the result was taken as an average.

3. RESULT AND DISCUSSION

Since the primary components of lignocellulosic feedstocks are cellulose, hemicellulose and lignin, information on the chemical composition of the feedstocks are very important for chemical and biochemical based products. Similar to other lignocellulosic material *Yushania alpina* also has lignin, cellulose and hemicellulose as primary components. In the utilization of bamboo in biomass energy production, the chemical composition and structure could have a significant effect on reactivity during chemical and enzymatic pretreatment, hydrolysis and fermentation.

Moreover, the chemical components of bamboo obtained from different locations or physiological ages, as well as within an individual bamboo culm, may show content variation. Hence, the real-time monitoring of the components is of great importance for the optimization of the biomass process (Xiaoli *et al.*, 2015).

3. 1. Ash and Moisture content in bamboo

Ash is the inorganic residue remaining after ignition at a high temperature. It is usually less than 1% of the wood from temperate zones and is slightly higher in wood from tropical climates (Song *et al.*, 2008). The ash content of bamboo is mostly silica, along with metals such as calcium and potassium (Li *et al*., 2007). According to our results, the moisture and ash content of *Yushania alpina* is 3.92 % and 3.77 % on average, the ash content is lower than of *Oxytenanthera abyssinica* grown in Ethiopia (Amsalu *et al.*, 2017) and highly agrees with that reported by (Kapu *et al.* 2014).

The chemical composition of *Yushania alpina* and different lignocellulose materials are shown in Table 2.

Table 2. The chemical composition of different lignocellulose material.

<table>
<tr><th rowspan="2">Analysis</th><th colspan="8">Species</th></tr>
<tr><th>Y. alpina</th><th>O. abyssinica</th><th>Bambusa blumeana</th><th>Bambusa pervariabilis</th><th>Bamboo</th><th>Softwood</th><th>Softwoods</th><th>Hardwood</th></tr>
<tr><td>Moisture (%)</td><td>3.92± 0.46</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Ash (%)</td><td>3.77 ± 0.86</td><td>5.30</td><td>-</td><td>-</td><td>0.9-4</td><td>0.1-1</td><td>-</td><td></td></tr>
<tr><td>Hot water</td><td>12.23 ± 1.21</td><td>6.80</td><td rowspan="2">8.0</td><td rowspan="2">5.6</td><td rowspan="2">6-13</td><td rowspan="2">1-24</td><td>-</td><td>-</td></tr>
<tr><td>Ethanol-toluene</td><td>3.93 ± 3.34</td><td>5.60</td><td>-</td><td>-</td></tr>
<tr><td>Lignin (%)</td><td>25.27 ± 1.52</td><td>22.47</td><td>27.1</td><td>28.7</td><td>21-31</td><td>25-39</td><td>25-35</td><td>18-25</td></tr>
<tr><td>Cellulose (%)</td><td>46.76 ± 1.09</td><td>52.06</td><td>41.9</td><td>39.5</td><td>38-51</td><td>40-45</td><td>40-45</td><td>40-55</td></tr>
<tr><td>Hemicell-ulose (%)</td><td>12.18 ± 1.01</td><td>16.90</td><td>22.9</td><td>24.6</td><td>-</td><td>-</td><td>20-30</td><td>20-35</td></tr>
<tr><td>Reference</td><td>This study</td><td>Amsalu et al., 2017</td><td colspan="2">Li et al., 2015</td><td colspan="2">Kapu et al., 2014</td><td colspan="2">Marriot et al., 2016</td></tr>
</table>

3. 2. Extractives in bamboo

The extraneous components in wood and bamboo are substances other than cellulose, hemicelluloses, and lignin. They do not contribute to the cell wall structure, and most are soluble in neutral organic solvents. Extractives are a variety of organic compounds including fats, waxes, alkaloids, proteins, simple and complex phenolics, simple sugars, pectins, mucilages, gums, resins, terpenes, starches, glucosides, saponins and essential oils. No solvent is known which is capable of dissolving these components in wood without a chemical attack. The solubility of wood in various solvents is a measure of the content of the extraneous component. No single solvent can remove all of the extraneous materials. Toluene is relatively nonpolar and extracts fats, resins, oils, sterols, and terpenes, while polar solvents like methanol and ethanol isolate polar components from the material. Therefore, the mixture of Ethanol-toluene is a more suitable solvent as most of the ether-soluble plus most of the organic materials insoluble in water can be extracted. Hot water extracts some inorganic salts and low molecular weight polysaccharides including gums and starches. Water also removes certain hemicelluloses such as the arabinogalactan gum present in larch wood (Song *et al.*, 2008).

Our results show that the ethanol-toluene extractive content of *Yushania alpina* is 3.93 % (Table 8). This result is less than that of *Oxytenanthera abyssinica* (Amsalu *et al.*, 2017) which is 5.60 %, and also that of the 6-13 % of other bamboo species (Kapu *et al.*, 2014). It is also less than that reported by Li *et al.* (2015) for *Bambusa blumeana* and *Bambusa pervariabilis*. This shows that *Yushania alpina* has less substance that can be extracted by using an alcohol-toluene mixture. The hot water extractives of *Yushania alpina* is 12.23% which is very high when compared to *Oxytenanthera abyssinica* as reported by Amsalu *et al.* (2017) and in a range reported for softwood and hardwood by Kapu *et al.* (2014). This variation on extractives content in bamboo is caused by factors such as the type of the species, environmental conditions, harvesting time, geographical locations and other ecological factors (Song *et al.*, 2008).

3. 3. Lignin content in bamboo

Lignin is a phenolic substance consisting of an irregular array of variously bonded hydroxyl- and metoxy-substituted phenylpropane units. The lignin content, according to our experiment, of *Yushania alpina* is 25.27%. This result is higher than that of *Oxytenanthera abyssinica* as reported by Amsalu *et al*, (2017) which is 22.47%. It is, however, less than *Bambusa blumeana* (27.1%) and *Bambusa pervariabilis* (28.7%) as reported by Li *et al.* (2015). It agreed highly with the lignin content reported by Marriot *et al.* (2016) for softwood and the results of the work of Kapu *et al.* (2014) which is 21-31% for most bamboo species.

3. 4. The cellulose content in bamboo

The carbohydrate portion of wood is comprised of cellulose and hemicelluloses. Cellulose is a polymer D-glucose consisting of linear chains of 1,4-β-bonded anhydroglucose units. The cellulose content of *Yushania alpina* is 46.76%. This result is less than that reported for *Oxytenanthera abyssinica* by Amsalu *et al.* (2017) and is in close agreement with 40-45% which is reported by Marriot *et al.* (2016) and to that of 38-51% reported by Kapu *et al.* (2014) for bamboo. The cellulose content of *Y. alpina* is higher than that reported by Li *et al.* (2015) for *Bambusa blumeana* (41.9%) and *Bambusa pervariabilis* (39.5%). The cellulose content of *Yushania alpina* gives information that it can be a suitable feedstock for cellulosic ethanol production.

3. 5. Hemicellulose content in bamboo

Hemicelluloses are mixtures of polysaccharides synthesized in wood almost entirely from glucose, mannose, galactose, xylose, arabinose, 4-O methylglucuronic acid and galacturonic acid residues. Some hardwoods contain trace amounts of rhamnose. Generally, hemicelluloses are of much lower molecular weight than cellulose and are branched in structure.

They are intimately associated with cellulose and appear to serve as a structural component in the plant. We found that the hemicellulose content of *Yushania alpina* is 12.18%, which is less than 16.90% of *Oxytenanthera abyssinica* as noted by Amsalu *et al.* (2017) and 20-30 and 20-35% for softwood and hardwood, respectively, as reported by Marriot *et al.* (2016). It is also relatively lower than that reported by Li *et al.* (2015) for *Bambusa blumeana* (22.9%) and *Bambusa pervariabilis* (24.6%).

4. CONCLUSION

The chemical composition of *Yushania alpina* bamboo was found to contain 46.76±1.09% cellulose, 25.27±1.52% lignin, and 12.18±1.01% hemicellulose. This result shows that *Yushania alpina* can be a potential feedstock for lignocellulose ethanol production since it has higher cellulose content.

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