**Characterization and Efficacy of Bio-oil Obtained from Liquefied Hardwood Bark as Wood Preservative**

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**Abstract**

The efficacy of bio-oil obtained via solvolysis liquefaction of *Detarium senegalense* J.F. Gmel bark as bio-preservative against fungi attack on *Gmelina arborea* wood was investigated, as a way of contributing to unrelenting researches aimed at achieving sustainable environment and preserving lignocellulosic materials. Ethanol, water and co-solvent of ethanol/water were used to directly liquefy *D. senegalense* bark at 300oC for 30min. The result of the structural compositional characterization reveals that, *D. senegalense* bark is composed of an average of 35.2% lignin, 46.8% cellulose and 18.0% hemicellulose. The result of the elemental analysis also showed that *Detarium senegalense* is composed of 53.82% carbon, 36.8% oxygen, 7.32% hydrogen, 0.14% nitrogen and 0.08% sulphur. Molecular weight characterization of the bio-oil as determined by the Gel Permeation Chromatography (GPC) revealed the bio-oils obtained from liquefaction using ethanol, water and ethanol/water mix had molecular weights of 15.56 x 102 Da, 14.17 x 102 Da, and 16.93 x 102 Da at an average respectively. Viscosity of the bio-oil obtained from liquefaction with ethanol/water was the highest and it was observed that viscosity increases as percentage concentration of the bio-oils increases. The FT-IR characterization of the bio-oils revealed the presence of primarily phenolic compounds and their derivatives such as benzenes, aldehyde, long-chain and cyclic ketones, alcohols, ester, organic acid, and ether compounds. Wood samples of *Gmelina arborea* of dimensions 50 x50 x 300mm were impregnated using vacuum method. The wood samples were exposed to brown rot fungi; (*Coniophora puteana*) for a period of 6 weeks. The percentage weight loss was determined. Maximum protection against the fungi was obtained using the co-solvent of ethanol/water at all the concentration levels.

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These results strongly suggested that synergistic effect of co-solvent of ethanol and water enhances the durability of *Gmelina arborea* wood at all levels of concentration. It was however, observed that high concentration does not implies ability to cause minimal weight loss in *Gmelina arborea* wood treated liquefied bio-oils. From this investigation, it was established that bio-oil obtained via solvolysis liquefaction of *Detarium senegalense* bark is a potential bio-preservative against fungi attack on of *Gmelina arborea* wood.

***Keywords:*** Detarium senegalense; weight loss; Gmelina arborea; solvolysis liquefaction; Coniophora puteana; co-solvent.

1. **Introduction**

Wood is one of the most frequently used materials for construction purposes world-wide. In Nigeria, more than 80% of timber products are used for constructional purposes such as building, furniture, railway sleepers, transmission poles, pulp and paper, plywood, veneers, composites board, matches, fuel (coal industry) and fuel wood [1]. The fact that wood can be used for both in-door and out-door services and exposed to different weather conditions shows that wood can be used for many years if properly preserved. However, due to the nature and character of wood, exploitation of tree for structure and construction purposes were selective and limited to strong and durable wood species [2]. Wood products in use throughout the world are subject to infestation by biodegrading agent one of which is fungi infestation that had resulted into loses of valuable wood, a proactive measure is therefore, directed towards their control. The conventional wood preservatives used to protect wood from insects and micro-organisms damages are presently of major concern to human health and the environment. The most common wood preservatives are the oil-based preservatives creosote and pentachlorophenol and the water-based preservatives chromated copper arsenate (CCA), amine copper quat (ACQ) among others. Although, these conventional wood preservatives are effective against bio-deterioration agents, however, they are costly, toxic and hazardous to the environment [3]. Recently, great interest has been focused on some wood preservatives that are relatively cost – effective and have minimal toxicity to mammals and the environment. Ability of bio-oil obtained via the use of water- a natural resources and ethanol-a liquid readily obtainable from the fermentation of sugar to protect wood against wood degrading fungi could be one possible approach to developing new wood preservatives. Biomass represents the cheapest and most abundant feedstock available in large volume. Approximately 117 billion tons (based on the oven dry material) of plant biomass, including by 80 billion tons in forests biomass is produced in the world annually [4, 5] Until recently, bark is treated as a waste, thus, little research are directed at studying the utilization of bark bio-oil as obtained from solvolysis liquefaction of bark as potential wood preservative. One of the processes that convert biomass into liquid chemicals begin with solvolysis liquefaction. Direct liquefaction of lignocellulosic materials in a suitable solvent at relatively lower temperatures, known as solvolytic liquefaction, is more advantageous than the pyrolysis processes with respect to energy efficiency and the quality of the oily products [6] As such, the solvolysis liquefaction technologies of lignocellulosic materials have attracted increasing interest for the production of bio-phenol precursors for chemicals and heavy oils (bio-crude) for bio-fuel production. The bio-oils obtainable from this process are mixture of benzenoid aromatic compound, alcohol, ester, various aldehydes, substituted furfural, benzaldehyde, phenolic compounds and their derivatives substituted ketones, piperazine, acetamide, n-dimethyl-formamide [20]. Because of their complex structure, it is presumed that the bio-oil obtainable via these process can protect wood against fungi attack. Bio-oil can be considered as an alternative to creosote. In contrast to creosote, bio-oil does not contain polynuclear aromatic hydrocarbons (PAH). It does contain many phenolic compounds that are effective against wood destroying fungi. PAH are dangerous pollutants, affecting the environment and humans' health, in addition to acting as irritants [7] Furthermore, bio-oils are composed of biodegradable compounds. *Detarium senegalense* is a leguminous tree in the [sub-family](https://en.wikipedia.org/wiki/Subfamily) [*Caesalpinioideae*.](https://en.wikipedia.org/wiki/Caesalpinioideae) Unlike most members of the family, it produces globular fruits [8]. *D. senegalense* is a medium-sized tree that may grow up to 40 m tall [8]. Like many trees in the *Caesalpinioideae*, they have thick, irregularly placed branches. The bark of *D. senegalense* was studied to sustainably utilize the wood bark in biorefineries and in tannin adhesives production. The study showed that *D. senegalense* had the highest bark abundance between and within species among wood species studied [9]. The mean bark percentage ranged from 6.08 % in *A. leiocarpus* to 15.00 % in *D. senegalense.* The objectives of this study is to determine theefficacy of bio-oil obtained from liquefaction of *D. senegalense* bark using ethanol, water, and ethanol/water mix as the liquefaction solvent at different concentration of 2.5, 5 and 7.5 % against brown rot fungi (*Coniophora puteana* attack on of *Gmelina arborea* wood

##### **2. Materials and Methods**

The biomass used in this study was bark of *D. senegalense* collected from Gambari forest reserve. Gambari Forest Reserve is located on latitude on latitude 7o7’ 60’’N and longitude 3o 49’ 60’’ E within the low land semideciduous forest belt of Nigeria and covers a total land area of 17,984ha [10].

***2.1. Ultimate, proximate and chemical compositional characterization of Detarium senegalense***

The bark samples of *D. senegalense* were dried in an oven at 105 oC for 24 hrs, and later hammer-milled after drying. The elemental composition of Carbon, Hydrogen, Nitrogen, and Sulphur in the depolymerized *D. senegalense* bark samples were analyzed with a CHNS Flash Elemental Analyzer 1112 series and using helium as a carrier gas

#### *2.2. Determination of lignin, cellulose and hemicelluloses content of Detarium senegalense bark*

Chemical compositional analysis of bark and liquefied bark residues, with the aim of determining the holocellulose, alpha-cellulose and lignin content was conducted. The extractive-free residues were first prepared according to [11] ASTM D1105-96.The lignin content was measured on the basis of standard procedures developed by the National Renewable Energy Laboratory (NREL) [12]. The cellulose, hemicellulose, and holocellulose contents were also measured by traditional wet chemistry analysis.

***2.3. Preparation of phenolic bio-oil from Detarium senegalense bark via solvent*** ***liquefaction***

The bark was hammermilled using New Holland grinder model 358, with 3.175-mm (1/8 in.) sieve size for particle reduction. It was then oven dried at 105 oC for 12 hrs and kept in a desiccator at room temperature before use. Solvolytic Liquefaction of the hammer-milled *D. senegalense* bark was carried out in a 1000 ml stainless steel autoclave reactor equipped with a mechanical stirrer (500 rpm) and a water-cooling coil the solvents used for the liquefaction was ethanol/water mix on weight-to-weight basis. In a typical run, the reactor was charged with 10 g *D. senegalense* bark and 100 g water or 100 g ethanol or ethanol/water co-solvent 50/50 %(v/v), after which the reactor was sealed, and the air inside the reactor was displaced by high-purity nitrogen. The reactor was pressurized to 2.0 MPa and heated to the desired temperature of 300 oC at a steady rate of 10 oC per minute while being constantly stirred. The reaction was stopped after 30 minutes completion of the liquefaction process. The reactor was cooled to room temperature of 25 oC by means of the water-cooling coil. The gaseous products (**GAS**) inside the reactor were thereafter vented. The resulting suspension inside the reactor was completely rinsed with acetone and collected in a glass bowl. The suspension was filtered under reduced pressure through a pre-weighted Whatman No. 5 filter paper to obtain the solid residue (**SR)** on the filter paper while the aqueous soluble products **(AP**),consisting of bio-oil, in the form of liquid oily product and other non-oily liquid products were obtained as filterate. The SR and filter paper were dried at 105 oC for 2 hrs before weighing. The acetone in the filtrate was then removed by rotary evaporation under vacuum at 40 oC. When co-solvent mixture of ethanol-water was used, this treatment removed the alcohol co-solvent in addition to acetone. The remaining liquid solution was extracted with ethyl acetate. Sepratory funnel was used to separate the liquid oily products, denoted as bio-phenolic oil from water and aqueous soluble products **(AP)**. Ethyl acetate soluble phase was then evaporated under a reduced pressure at 57 oC to remove ethyl acetate; and recover the remaining aqueous soluble product **(AP)**. Yield of bio-oil, SR was calculated by the percentage weight of the mass of each product to the mass of the dry *D. senegalense* bark loaded into the reactor at each run. The biomass conversion was simply calculated using (Equation 2).

***2.4. Measurement of the Bio-oil yield***

The yield of the Bio-oil was quantified as:

*Weight of bio-oil*

*% Bio-oil yield = x 100* (1)

*Weight of oven-dried raw D.senegalense*

 *bark before liquefaction*

## *2.5. Chemical characterization of the bio-oils*

### *2.5.1. Molecular characteristics of bio-oils using Matrix-Assisted**Laser Desorption/Ionization-Time-of-Flight Spectrometer (MALDITOF)*

Weight average molecular weight (*Mw*), number average molecular weight (*Mn*) and polydispersity index (*Mw/Mn*) of the liquefied oils were measured by a Matrix-Assisted Laser Desorption/Ionization Time of-Flight spectrometer (MALDITOF) at the Biosystems, Eng. Dept. Auburn University, Alabama. USA. The samples were prepared with THF (Tetrahydrofuran) as the matrix. The matrix solution was obtained by mixing the matrix material in 50 % aqueous ethanol and 0.1 % trifluoroacetic acid to give a 10 mg/ml concentration. The matrix solution was then mixed with each prepared resin sample at a ratio of 4:1 (v/v), of resin to matrix solution. 1 µL of the mixture was subsequently added on the MALDI target and air dried. Each spectrum was collected by the total number of ions from 500 laser pulses. The average molecular weight and polydispersity index were calculated using the method of Hills and Urbach as reported by [13]

***2.6. Impregnation process***

*Gmelina arborea* of dimensions 50 x 50 x 300mm samples were treated with the bio-oils at different concentrations (2.5, 5.0, and 7.5mg/g). The impregnation was carried out in a small scale impregnation container using a vacuum of 650 mm/Hg for 30 mins at atmospheric pressure for 15 mins. Afterwards the samples were conditioned at 20 o C and 65 % RH for 1 weeks. Retention of bio-oils were calculated with Equation (2)

R= [(G x C) / V] x10 g/cm3 (2)

Where R is retention, G is the difference between sample weight before and after the impregnation, C is concentration of bio-oil (%), and V is volume of samples.

***2.7. Decay resistance test***

Untreated (control) *Gmelina arborea* wood and treated *Gmelina arborea* wood samples were exposed to Coniophera puteana (Schumach.) P. Karst. (Mad-515) brown-rot fungi according to [14]. The fungi were cultured on 4.8% malt extract agar (MEA) medium. The media was steam sterilized at 120 o C for 20 mins before it was poured into each petri dish. After inoculation, petri dishes were kept at 23±2 o C and 65±5 % relative humidity until fungi completely covered the dishes. Following the test, the control samples’ oven-dried weights were determined. Each of them steam sterilized at 120 o C for 20mins. Two controlled and treated samples replicated two times making 20 samples altogether were exposed to fungal testing. After the six weeks of exposure, the weight loss of both untreated (control) and treated samples was calculated from the dry weight before and after the treatment.

**3**. **Results**

 **Table 1:** Ultimate and structural compositional characterization of D. senegalense bark.

|  |  |
| --- | --- |
| **Ultimate Analysis, wt%** |  |
| C | 53.82 |
| H | 7.32 |
| N | 0.14 |
| S | 0.08 |
| Od | 36.8 |
| **Structural composition, wt%** |  |
|  |  |
| bTotal lignin | 35.2 |
| dCellulose | 46.8 |
| dHemicelluloses | 18.0 |

Note: a On a dry basis; b Determined by thermogravimetric analysis (TGA) in N2 at 10oC/min to 900oC; c On a dry and ash-free basis; d By difference;

**Figure 1:** Effect of solvent types on the yield of Bio-oil from the liquefaction at 300 oC while the solvent-to-biomass ratio was fixed at 10:1 (wt/wt)

**Table 2:** Mass loss (g) and retention (g/cm3) of treated and untreated *Gmelina arborea* wood against fungi

|  |  |  |  |
| --- | --- | --- | --- |
|  **Liquefaction Solvent** | **Concentration of extracts** | **Oil Retention (g/cm3)** | **Mass loss Treated (g)** |
| ***Coniophera puteana*** |
| **Ethanol** | 2.5 | 17.82 | 12.05 |
|  | 5.0 | 14.67 | 11.55 |
|  | 7.5 | 12.33 | 11.88 |
| **Water** | 2.5 | 17.88 | 11.66 |
|  | 5.0 | 14.77 | 11.22 |
|  | 7.5 | 10.77 | 11.35 |
| **Ethanol/Water** | 2.5 | 12.66 | 10.67 |
|  | 5.0 | 11.88 | 9.67 |
|  | 7.5 | 8.66 | 9.85 |
| **Mass loss of Control** |  |  | 46.67 |

From Table 1. It was observed that *D. senegalense* bark gave an average of 35.2% lignin, 18.0% hemicelluloses and 46.8% a-cellulose. The % lignin, cellulose and hemicellulose contents in *D. senegalense* does not differ significantly from that of hardwoods [15]. The bio-oil yield recorded via liquefaction with ethanol, water and ethanol/water mix were 45, 30, and 25%, respectively. A uniform particle size of (1/8mm) was used for all experiments, since the particle size significantly affects the yields of liquefied product products. The elemental analysis of *D. senegalense* bark showed that the bark component contained 53.82% carbon, 36.8% oxygen, 7.32% hydrogen, 0.08% sulphur and 0.14% nitrogen. Sulphur and nitrogen compounds were reduced to the barest minimum, which invariably implies safer environmental conditions associated with products obtained from depolymerized *D. senegalense* bark. The nitrogen and sulphur compounds detected were likely to originate from the fuel-bound nitrogen and sulphur in the *D. senegalense* bark. The high heating temperature of 300 °C could have contributed to the slight increase of the bio-oil yield aside other factors. From Figure, 2 however, it was generally observed that bio-oil obtained from liquefaction with water had the highest rate of retention in the wood. This could be attributed to its low viscosity and relatively lower molecular weight Table 3, when compared to bio-oil obtained from ethanol and ethanol/water mix. It was however, observed that high concentration does not implies ability to cause minimal weight loss in *Gmelina arborea* wood treated with liquefied bio-oil. The FT-IR spectra for the bio-oils from the liquefaction using different solvents is illustrated in Figure 2. It was observed that all of the bio-oils displayed similar IR adsorption profiles, suggesting similar chemical structures. They all had the typical hydroxyl groups absorption at 3402 cm-1 which was caused by the combination and overlap of aliphatic and aromatic O-H stretching from the phenolic compounds as well as from the moisture inevitably contained in the samples, and the adsorption between 1715 cm-1 and 1738 cm-1 may be ascribed to the C=O stretching from ketone, aldehyde and ester groups [16]. The presence of both O-H and C=O stretching vibrations may also indicate the present of carboxylic acids and their derivatives. Absorption between 2845 cm-1 and 2945 cm-1 could be attributed to symmetrical and asymmetrical C-H stretching vibration of methyl group and methylene group. The band at 1379 cm-1 was attributed to C-H bending. The C-H stretching vibration and C-H bending indicate alkane groups in the bio-oil. Bands from 1447 cm-1 to 1612 cm-1 belonged to the aryl groups, and the adsorption band at 1612 cm-1 was likely by benzene backbone vibration. The absorption peaks between 1000 cm-1and 1300 cm-1 were attributed to the C-O stretching and O-H deformation vibrations which described the present of primary, secondary and tertiary alcohols, phenols, ethers and esters [17, 18]. The broad absorption peaks at 1250 cm-1 were likely attributed to methoxyl group. Meanwhile, the bands between 690 cm-1 and 950 cm-1 indicated the presence of single, polycyclic and substituted aromatic groups [16].

**Table 3:** Physical properties and molecular characterization of bio-oils

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Liquefaction Solvent** | **Concentration** **( %)** | **PH** | **Viscosity****(Cp)**  | ***MW*****(Da)** | ***Mn*** | **Polydispersity****Ratio (*MW*/*M*n)** |
| **Ethanol** |  2.5 7.54 192 14.40x102  7.48x102 1.93 5.0 7.45 210 15.32x102  6.70x102 2.29 7.5 7.02 225 16.97x102  6.56x102 2.58 |
| **Water** |  2.5 7.67 188 13.78x102 6.25x102 2.20 5.0 7.32 195 13.98x102 6.32x102 2.21 7.5 7.22 198 14.76x102 6.44x102 2.29 |
| **Ethanol/Water** |  2.5 7.82 205 15.65x102 6.75x102 2.32 5.0 7.88 235 17.15x102 7.11x102 2.41 7.5 8.01 245 17.98x102 7.32x102 2.46 |

From Table 3, viscosity of the bio-oil obtained from liquefaction with ethanol/water was the highest. Another noticeable observation was that, viscosity increases as percentage concentration of bio-oil increased. This variation could be attributed to the larger molecular weights and complex molecular structures of compounds present in the bio-oil. Low resin viscosities results in high retention of the bio-oil in the treated wood sample while too high viscosities results in low bio-oil penetration/ retention (Table 2). It was also observed that as the viscosity increases, the molecular weight (*Mw*) of the bio-oil also increased. These could be as a result of the presence of some larger molecular compounds, i.e. degraded bark. Wood impregnation with higher concentration of bio-oil usually have increase molecular weight the same scenario has been reported for wood treated with, higher concentration of resin synthesized using liquefied bio-oil of different concentration [19]. A similar trend was observed by [20] with bio-oil, having medium (470 Da) and high (820 Da) molecular weight not penetrating the wood cell wall and did not fill the cell lumens instead resin granules were observed on the inner wall of wood cell, the same trend must have applied for the bio-oils used in this study. The ethanol/water liquefied bio-oil, having molecular weight ranging between 1715 x102 and 1798 x102 Da, probably did not penetrate the wood cell walls enough in a significant way. Liquefied bio-oil granules similar to those observed by [20], after treatment with a medium molecular weight m-bromophenol-formaldehyde resin was also observed on the surface of *Gmelina arborea* cell walls when viewed under microscope. Bio-oil uptakes are known to increase the durability of wood [21]. However, results obtained here do not support that claim with bio-oil obtained from liquefaction with water and ethanol even though were retained better causes high mass loss on the average than the bio-oil obtained from liquefaction with ethanol/water mix. This result suggested that the bio-active phenolic compound that was absorbed in the cell wall most especially, from the 7.5% concentration of ethanol/water liquefied bio-oil was more efficient in protecting *Gmelina arborea* wood form fungi attack



**Figure 2:** Functional group characterizations of bio-oil obtained via solvolysis liquefaction using ethanol, water, and ethanol/water mix

## *3.1. Effects of solvent types on bio-oil yield.*

Water was observed to be more effective than Ethanol when both mono-solvents were evaluated Figure 1. Liquefaction with 100 % water yielded 46 % by weight of the bio-oil, compared with 30 % by weight of bio-oil yield when 100 % ethanol was used. The result however, show that 50/50 % (v/v) ethanol/water mix for the solvolysis liquefaction of D. *senegalense* bark yielded 52 % bio-oil and could therefore be said to be much more effective than mono-solvent of either water or ethanol. The result was almost similar with the work of [22] where white pine sawdust was effectively liquefied in 50 wt% ethanol-water medium, producing approximately 66 wt% bio-oil. The differences in the bio-oil yield obtained from the solvents could be ascribed to the fact that alcohols are slightly weaker acids than water. However, it has been established that water in hot-compressed and sub-critical state has many special properties some of which are; having a lower dielectric constant, fewer and weaker hydrogen bonds, a higher isothermal compressibility and an enhanced solubility for organic compounds than ambient liquid water [23, 24], and as a result, lower activity of 100 wt% ethanol for biomass liquefaction than that of 100 % water may be expected. In addition, hot-compressed water had been demonstrated to be an effective solvent for biomass hydrothermal liquefaction [25, 26, 27]. It has also been found to be very effective for promoting ionic, polar non-ionic and free-radical reactions [24], which make it a promising reaction medium for biomass direct liquefaction. Ethanol also, been reported to having the ability to readily dissolve relatively high-molecular-weight liquid products/intermediates derived from cellulose, hemicelluloses, and lignin because of their lower dielectric constants when compared to that of water [28, 29].The lower yield of bio-oil in ethanol than water however, could be due to limited hydrolysis reaction. However, co-solvent of ethanol-water was a much more effective solvent than any constituent mono-solvent**.** These results strongly suggested synergistic effect on biomass direct liquefaction observed when the co-solvent of ethanol and water produced a higher yield of bio-oil as previously reported by [30, 31] in organosolv delignification of woody biomass at 190 oC where 50 % methanol to water solution or 50 % ethanol to water solution was found to be very effective for wood delignification;. The co-solvent of ethanol to water has attracted more interests, simply because ethanol is a renewable resources, which can be obtained readily by fermentation of sugars. However, as the concentration increased, the viscosity increased, the molecular weight increased and this caused the the retention amount parallel to liquid concentrations to decrease. Mass losses caused by *C. puteana* on *Gmelina arborea* wood samples treated with bio-oil obtained via solvolysis liquefaction using ethanol, water and ethanol/water mixture at the 3 different concentration levels are shown in Table 2. The mass losses of untreated control samples exposed to *C. puteana*, was 46.67g. When the mass losses of test wood samples at different concentration of the liquefied solvent and control specimens were examined, it was observed that wood protection is not always provided with the highest level concentration of preservatives [32]. Above 5% concentration, the bio-oils showed an opposite effect against *C. puteana* fungi. The lowest mass loss was realized at 5% concentration. All treated samples had significantly lower mass loss than the untreated control samples. The decay resistance of the treated wood samples with 5% bio-oil against brown rot fungi was very effective. However, the average retention of bio-oil at this level was 11.88 to 14.77g/cm3, which was industrially applicable and relatively cheaper than the full cell treatment. Maximum protection against the fungi was obtained using the co-solvent of ethanol/water at all the concentration levels. These results strongly suggested that synergistic effect of co-solvent of ethanol and water in enhancing the durability of *Gmelina arborea* wood at all levels of concentration. From this investigation, it was established that bio-oil obtained via solvolysis liquefaction of *Detarium senegalense* bark is a potential bio-preservative against fungi attack on of *Gmelina arborea* wood. The decay resistance of the treated wood samples with bio-oil against *C. puteana* brown fungi can be attributed to the phenolic compounds in the bio-oil. It was reported that phenolic compounds are the main active compounds for antimicrobial activity [33, 5]

**4. Conclusion**

Characterization and The efficacy of bio-oil Obtained from Liquefied Hardwood Bark as bio- Preservative

Of *Gmelina arborea* wood against brown rot fungi (*Coniophora puteana*) were evaluated in this study. At the end of the research it can be concluded that

* Bio-oil was obtained by solvolysis liquefaction process at 300oC and the structural compositional characterization reveals that, *D. senegalense* bark is composed of an average of 35.2% lignin, 46.8% cellulose and 18.0% hemicellulose, the elemental analysis also showed that *Detarium senegalense* is composed of 53.82% carbon, 36.8% oxygen, 7.32% hydrogen, 0.14% nitrogen and 0.08% sulphur
* The identified compounds in the bio-oil were acids, ketones, aldehydes, furans, benzenes, phenols, sugars, guaiacols, and multifunctional compounds.
* When the solvent concentration were holistically evaluated, it could be reported that the decay resistance of treated wood samples with 5% concentration of bio-oil against brown fungi (*Coniophora puteana*) was very effective.
* Phenolic compounds in the bio-oil made up the main group of compounds and played a significant role in the increased decay resistance against brown rot fungi.
* The high molecular weight of ethanol/water liquefied bio-oil affected their retention and probably did not penetrate into the wood cell walls enough in a significant way.
* Even though ethanol/water liquefied bio-oil did not penetrate well into the cell wall of *Gmelina arborea* wood, the little amount of bio-oil that was retained was most effective enough against brown fungi (*Coniophora puteana)* when compared with liquefaction with ethanol or water and was able to cause a significant reduction in the weight loss

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