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Physicochemical properties of lignocellulosic biofibres from South Eastern Nigeria: Their suitability for biocomposite technology

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Five plant raw materials collected from South Eastern part of Nigeria were used for biofibre extraction and analysis to assess their suitability for biocomposite production. Lignocellulosic biofibres were extracted from young stems of *Adenia lobata, Ampelocissus leonensis*, *Cissus palmatifida, Morinda morindoides* and *Urena lobata* through natural water retting process for a period of 14 - 16 days and the resulting fibres were uniform with almost flat or circular cross sections. Phytochemical contents and extractives were determined on the untreated and treated fibres respectively. The %w/w cellulose contents of the pretreated biofibres were found to be 48.97± 1.33% for *A. leonensis* and 43.22±0.95% for *A. lobata*. The cellulose content of *M. morindoides* and *C. palmitifida* were found to be 55.76±1.40% and 55.20±1.59%, respectively. In all the plants studied, *U. lobata* had the greatest %w/w cellulose content of 58.94±1.05% while *A. lobata* had the least cellulose content of 43.22±0.95%. Estimation of %w/w hemicellulose contents showed *A. leonensis* to be 21.22±0.89% whilst the hemicelluloses content in *A. lobata* and *U. lobata* were observed to be 18.22±2.18% and 12.38±0.33% in that order. Lower hemicelluloses contents were obtained in *C. palmitifida* and *M. morindoides* as 10.32±1.27, 9.32±0.58 and 8.62±1.67%, respectively. The klason lignin contents were found to be 31.33±1.05% for *C. palmitifida*, 31.22±0.97% for *M. morindoides*, 28.22 ± 1.96% for *A. lobata*, and 24.91±0.61% for *A. leonensis*. The lignin content of *U. lobata* was found to be the least at 22.26±0.55%. Acid soluble lignin (ASL) content was greater in *A. lobata* (2.17±0.08%) while *A. leonensis* had the least value of 1.74±0.34%. ASL-derived products (vanillin, p-coumaric acid and ferulic acid) ranged between 0.50±0.12% and 1.41±0.02% for vanillin; 0.03± 0.02% and 0.65±0.14% for p-coumaric acid; and ferulic acid was only detected in *A. leonensis* as 0.41±0.11%. The mechanical properties of most fibres used in this study are comparable to those of other biofibres already used in manufacturing and can even match those of some synthetic fibres. Results obtained revealed that fibres used in this study had comparable properties with those already established for manufacturing in biofibre industries.

Key words: Biofibre, biocomposite, cellulose, lignin, hemicelluloses.

INTRODUCTION

In 1989, the German DLR Institute of Structural Mechanics developed an innovative idea. By embedding natural reinforcing fibres for example flax, hemp, and ramie into biopolymeric matrix made of derivatives from cellulose,

starch, lactic acid; new fibre reinforced materials called biocomposites were created and are still being developed (Mohanty et al., 2000). Biocomposites consist of biodegradable polymer as matrix materials and usually biofibres as reinforcing element. Biofibres (natural polymers) are generally biodegradable but they do not possess the necessary thermal and mechanical properties desirable for engineering plastics (Mohanty et al., 2000). A lot of research and development efforts had been carried out on biofibre reinforced synthetic polymers. The composites of biodegradable natural fibres and non-biodegradable synthetic polymers may offer a new class of materials which however are not completely biodegradable (Mohanty et al., 2000).

Biocomposites are finding applications in many fields ranging from the construction to automotive industries. The use of plant fibres in composites had increased due to their relative low cost, recyclability and the fact that they compete well in terms of strength per weight of material (Maya and Sabu, 2008). Natural fibres are considered as composites consisting mainly of cellulose fibrils embedded in lignin matrix. The cellulose fibrils are aligned along the length of the fibre which renders maximum tensile and flexural strengths thereby providing rigidity to the fibre. Thus, the reinforcing efficiency of natural fibre is related to the nature of cellulose and its crystallinity (Maya and Sabu, 2008). Most plant fibres, except for cotton, are composed of cellulose, hemicellulose, lignin, waxes, and some water-soluble compounds, with cellulose, hemicelluloses, and lignin as the major constituents (Taj et al., 2007). Depleting natural resources, regulations on using synthetic materials, growing environmental awareness and economic considerations are the major driving forces to the utilization of annually renewable resources such as biomass for various Industrial applications (van Wyk, 2001). Approximately 2×10^{11} tons of lignocellulosics are produced every year, compared with 1.5×10^{8} tons of synthetic polymers (Mohanty et al., 2000). These lignocellulosic agricultural byproducts could be principal sources of fibres, chemicals and other industrial products.

The various applications of lignocellulosic materials depend on their chemical composition and physical properties. Wheat, rice straw and corn stalks to a limited extent, have traditionally been used for pulp and paper making while coconut fibre (coir), pineapple and banana leaves have been used as natural cellulose fibre source for making textiles, composites and paper (Majumdar and Chanda, 2001). Recently, natural cellulose fibres suitable for textile and other industrial applications have been produced from corn husks and corn stalks (Reddy and Yang, 2004). Rice and wheat straw have also been used to produce regenerated cellulose fibres as an alternative to wood for cellulose-based materials (Lim et al., 2001). Increase in fuel costs and scarcity of petroleum sources led to the use of lignocellulosics to produce ethanol and other sugars by fermentation; biomasses can also be converted into carbon, hydrogen and oxygen to produce various chemicals, enzymes and proteins (Reddy and Yang, 2005).

In our former study, the biocomposite potentials of *Ampelocissus cavicaulis* a highly fibrous plant domestically used as twine was highlighted (Agu et al., 2012). In the present study, novel plant fibres locally used for various applications were sourced, identified, characterrized and their potentials for use in biofibre technology were investigated. Fibre bundles from the stems of these plants are traditionally used in making sponge, mat and twine; thereby emphasizing their immense potential as industrial raw materials.

MATERIALS AND METHODS

Raw materials extraction

Five species of woody plants were selected for the study: *Adenia lobata, Ampelocissus leonensis*, *Cissus palmatifida, Morinda morindoides* and *Urena lobata*. The stems of the above species are locally made into twine in south eastern Nigeria. The parent plants were identified and the vouchers were also deposited at the Bioresources Development and Conservation Programme (BDCP) Research Centre, Enugu, Nigeria. Stems freshly cut from young plants (< one year old) were allowed to ret in a flowing stream (natural water retting) for a period of 14-16 days. During the retting process, the tissue that interconnects the single fibres that is the middle lamella are degraded by microbial activity to yield strands of natural plant fibre after which the materials were macerated to remove the remaining stem bark and other foreign materials. Extracted fibres were sun dried after which they were milled into powder using Safar miller SNE-200 machine.

Pretreatment of natural fibres

Pretreatment of the natural fibres was done using the Soxhlet technique. This procedure was carried out in order to remove lipophilics (gums and waxes) and residual phytochemicals remaining after the retting process (especially tannins) that could interfere with the determination of the structural components of the biofibres. This method also allows for the determination of extractives (lipophilic and alcohol) at the same time. It is based on the initial preatment of the samples with n-hexane to remove the lipohilics and then methanol to remove the polar substances. Milled biofibres (100 g) were properly packed into the thimble of the soxhlet extractor, and n-hexane (300 ml) was poured into the round bottomed flask of the soxhlet extractor. The complete soxhlet extractor (ithat with its condenser) was then mounted on a heating mantle which had its temperature guage set at 70°C. The above experiment was repeated using methanol (300 ml; 40 - 60°C) as the extracting solvent. The percentage yields of the lipophilic and methanol extractives

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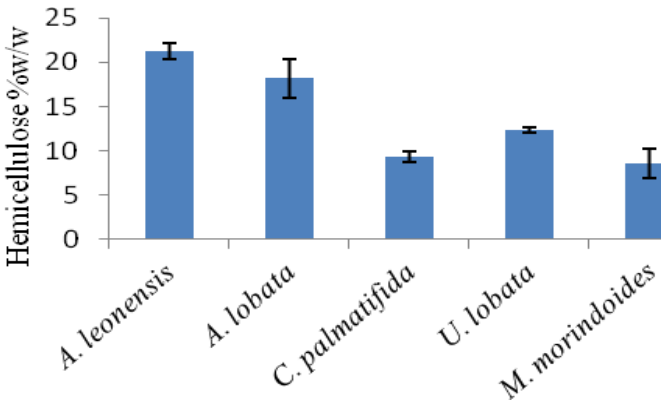

Figure 1. Hemicellulose content of fibres in %w/w basis (Error bars refer to 95% JSCI).

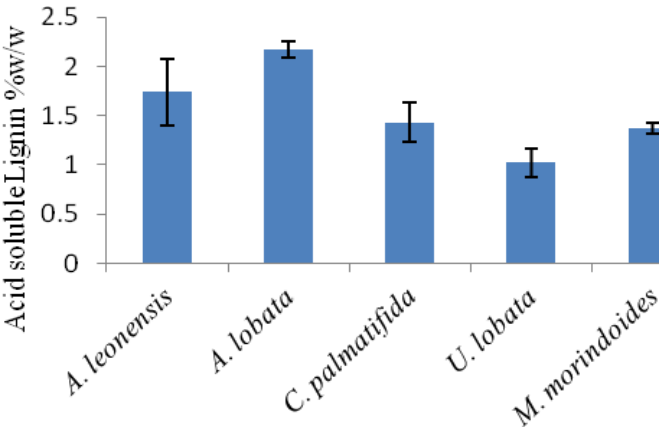

Figure 2. Acid soluble lignin contents of fibres in %w/w basis (Error bars refer to 95% JSCI).

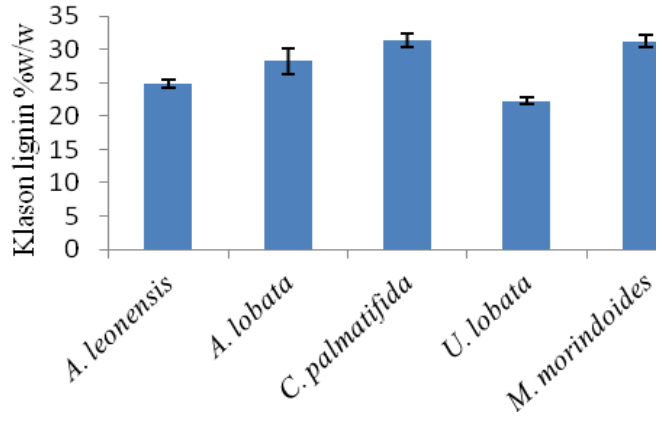

Figure 3 Acid insoluble (Klason) Lignin contents of fibres (Error bars refer to 95% JSCI).

were determined after triplicate run and the mean values reported.

The pretreated samples were removed from the thimble, oven dried at 90°C for 3 h to remove solvents and subsequently characterized.

Chemical analysis

Phytochemical analysis

The untreated fibres were analysed for the presence of phytochemicals including tannins, alkaloids, flavonoids, saponins, glycosides, proteins, reducing sugars terpenoids and steroids. This was done using the methods developed by Harborne (1998).

Analysis of chemical (structural) compositions

Lignin, ash, cellulose, hemicellulose contents were determined as follows; Kurshner and Hoffer cellulose was determined using the method described by Kurschner and Hoffer (1933) as adopted by Beakou et al. (2008). A quantity (0.7 g) of the pretreated sample was added with a 95% solution of nitric acid and ethanol. The mixture was filtered and the residue washed first with hot water then with absolute ethanol to completely remove the acid. The cellulose corresponds to the insoluble fraction of the mixture. The residue was oven dried at 100˚C to a constant weight. The test was run in triplicates and the mean value reported.

The neutral detergent fibre method of Goering and van Soest (1975) was adopted for determining the hemicellulose content of the samples. Neutral detergent fibre was prepared by refluxing for one hour a quantity, 0.7 g of each fibre sample with 10ml of cold neutral detergent solution and 0.5 g of sodium sulfite (Figure 1). The mixture was subsequently filtered through sintered glass crucible (G-2) after which the residue was washed with hot distilled water and ethanol. The residue was subsequently oven dried to constant weight at 100°C for 8 h. The weight obtained is the neutral detergent fibre weight. The test was run in triplicates and the mean value taken. Hemicellulose content was calculated as the difference in weight of neutral detergent fibre and the acid detergent fibre prepared from acid hydrolysis of the same mass of sample. The hemicellulose was determined in triplicate run and the mean value was reported.

The standard method described by the Technical Association of Pulp and Paper (1998) was adopted for the estimation of acid soluble (or Klason) lignin and ash contents (Figure 2). A quantity, (0.7 g) of each pretreated fibre sample was boiled with 5 ml of 72% w/w H_2SO_4 solution for 4.5 h in order to hydrolyse the cellulose and hemicellulose. The suspension remaining after the above treatment was filtered through a crucible and thoroughly washed with hot distilled water and absolute ethanol to completely remove the acid present. The solid residue was dried at 105°C for 24 h and weighed (W1). This residue is known as the acid detergent fibre. The residue was then transferred to a pre-weighed dry porcelain crucible and heated at 600°C for 5 h. After cooling, it was weighed (W2) and ash content (%) was determined. Acid insoluble lignin was then calculated by the difference (W1 - W2). The test was run in triplicates and the mean value reported (Figure 3).

The method described by Hyman et al. (2008) was adopted for determination of acid insoluble lignin and its derived products. The method is based on boiling a quantity; 0.7 g of each pretreated fibre sample with 5 ml of 72% w/w H_2SO_4 solution for 4.5 h in order to hydrolyse the cellulose and hemicellulose. The suspension remainning after the above treatment is filtered through a crucible. The filtrate from acid hydrolysis above will be diluted with distilled water and the dilution factor was noted. Using UV-Visible Spectrophotometer, the absorbance at a wavelength of 205 nm was taken and the ASL calculated using the formula below. ASL-derived products-Vanillin, p-coumaric acid and ferulic acid were determined at different wavelengths of 230, 308 and 322 nm corresponding to

a: *A. leonensis* b: *A. lobata* c: *C. palmitifida* d: *M. morindoides*

Figure 4. Retted bast fibre bundles.

their wavelengths of maximum absorption respectively. Each parameter was run in triplicate and the mean value was recorded. The acid soluble lignin was calculated on extractives free basis using the formular;

$$\%\,ASL = \frac{UVabs \; x \; Volume_{filtrate} x \; Dilution}{\varepsilon \, x \, ODW_{sample}} \; x \; 100$$

Where, UVabs = average, UV – V is absorbance for the sample at specified wavelength, $Volume_{hydrolysis\ liquor}$ = volume of filtrate, 87 ml, ε= absorptivity constant of biomas at specific wavelength in L/g-cm.

The absorptivity constant ε was obtained using the Beer's law; $A_\lambda = \varepsilon bc$; A_λ = average UV-Vis absorbance at a specific wavelength; ε = absorptivity constant at a specific wavelength in L/g-cm; b is the path length through the sample in cm; c is the concentration of a single analyte in mg/ml.

Analysis of mechanical properties of the fibres

Three mechanical properties (tensile strength, Young's modulus and elongation at break) were selected for the study. Hounsfield Tensometer testing machine (model 5566) was used to determine the tensile strength, Young's modulus and elongation at break of the specimens. After finding the average diameter (D) of the fibres, the cross sectional area of each individual fibre can be determined using the formular;

Cross sectional area, $A = \pi r^2$, Where A = cross sectional area; r =D/2; D = diameter; π = 3.142

Chemical modification of fibre surface hydroxyl group

Alkali treatment is a chemical method, which can change the constituents of fibres. The procedure described by Bledzki and Gassan (1999) and Cao et al. (2007) was used. Fibres were soaked in 15 wt% NaOH solutions at room temperature for 2 h, maintaining a liquor ratio of 20:1. The fibres were washed several times with water to remove any alkali solution sticking to the fibres surface, neutrallized with dilute acetic acid and then washed again with water. Finally, the resulting fibres were dried at 70°C for 72 h.

Design and production of composites

The method of Yuhazri et al. (2010) was adopted. Productions of the composite samples were prepared using facilities at the Center for Composite Research and Development, JuNeng Nigeria Limited, Nsukka. Randomly oriented fibre reinforced bio-composites were prepared by taking different dimensions and percentages of the untreated, silane treated and alkaline treated fibres. Fibre/resin matrix composite laminates were prepared using a combination of hand lay-up and compression moulding method. The surfaces of moulds were first coated on the inside with universal mould release wax to avoid adhesion of the mixture and to allow easy removal of the composites. After thorough mixing of the resin with 0.4 wt-% methyl ethyl ketone peroxide (MEKP) solution with dimethylpthalate as catalyst and 0.3 wt% of cobalt derivative as accelerator, the mixture was poured into the moulds and the fibres added. The moulds were then closed and kept under pressure with a load of about 50 kg for 24 h. Subsequently, this cast is post cured in the air for another 24 h after removing the mould. Specimens of suitable dimension are cut using a diamond cutter for mechanical testing. Neat resin composites were also made as a control sample.

RESULTS AND DISCUSSION

Extracted fibre bundles

The following results were obtained after extraction of fibre bundles using natural water retting technique. The fibre bundles were uniform with almost flat and circular cross sections (Figure 4a, b, c and d).

Phytochemical analysis of untreated fibre bundles

The results obtained from the phytochemical analysis of the untreated plant fibres presented in Tables 1 and 2 shows moderate presence of steroids, tannins, proteins and alkaloids, and total absence of flavonoids and reducing sugar. Further analysis showed that *C. palmitifida* had the highest alkaloids concentrations of 7.09±0.04 mg/g. Moderate amount of residual tannins and steroids were obtained, with the values ranging between 0.01 - 0.03 mg/g in all the fibres analysed. Determination of phytochemical content has economic value during bio-fibre process. It gives an idea of how much pretreatment will be required. The absence of reducing sugars in this study suggests that the retted fibre were well protected from hydrolytic activity of the ambient environment and may explain the non-easily hydrolysable fibre materials

Table 1. Qualitative phytochemical analysis of the plant fibres.

Sample	Alkaloid	Flavonoid	Tannin	Steroid	Reducing Sugar	Protein
Ampelocissus leonensis	+	-	++	+	-	+
Adenia lobata	+	-	+	+	-	-
Cissus palmitifida	++	-	+	+	-	-
Urena lobata	+	-	++	-	-	-
Morinda morindoides	+	-	+	+	-	-

Table 2. Quantitative phytochemical analysis of the plant fibres.

Sample	Common name	Alkaloid (mg/g)	Tannin (mg/g)	Steroid (mg/g)
Ampelocissus leonensis	Okpaowoko	5.61 ± 0.071	0.02 ± 0.001	0.01 ± 0.001
Adenia lobata	Usoro	4.60 ± 0.028	0.01 ± 0.002	0.02 ± 0.001
Cissus palmitifida	Okpote	7.09 ± 0.04	0.01 ± 0.007	0.01 ± 0.002
Urena lobata	Abari/ udo	n.d	0.03 ± 0.001	n.d
Morinda morindoides	Ogbuebo	4.10 ± 0.11	0.01 ± 0.002	0.02 ± 0.002

n.d = not determined.

Table 3. %w/w Extractives, ash and moisture contents of retted fibre bundles.

Sample	Common name	Lipophilic extractives (%w/w)	Alcohol extractives (%w/w)	Ash (%w/w)	Moisture content (%)
Ampelocissus leonensis	Okpaowoko	0.27 ± 0.001	0.98 ± 0.002	0.57 ± 0.10	3.21 ± 0.05
Adenia lobata	Usoro	1.86 ± 0.61	5.64 ± 0.32	2.57 ± 0.08	5.50 ± 0.01
Cissus palmitifida	Okpote	0.12 ± 0.01	0.26 ± 0.001	2.14 ± 0.14	0.51 ± 0.18
Urena lobata	Abari/Udo	4.07 ± 0.02	10.22 ± 0.31	0.42 ± 0.06	2.61 ± 0.02
Morinda morindoides	Ogbuebo	0.21 ± 0.01	2.12 ± 0.11	2.46 ± 0.14	0.43 ± 0.21

Results expressed as mean ± S.D; n = 3.

obtained in this study.

Results for chemical analysis of the extracted fibres

Extractives, moisture and ash contents

From the results in Table 3, the highest amount of lipophilic extractives and alcohol extractives were found in *U. lobata* (4.07 ± 0.02 and 10.22 ± 0.31%) respectively whilst the least values were found in *C. palmatifida* (0.12 ± 0.01 and 0.26 ± 0.001%) and *A. leonensis* (0.27 ± 0.001 and 0.98±0.002%) respectively. *A. lobata* and *A. leonensis* had the greatest moisture contents at 5.60±0.071, 5.50±0.01, and 3.21±0.05%, respectively. Lower moisture contents were recorded for *M. morindoides* (0.43 ± 0.21%), and *C. palmitifida* (0.51 ± 0.18%). The ash content of *C. palmitifida* (2.14 ± 0.14%) was found to be greater than *A. leonensis* (0.57 ± 0.10%) and *U. lobata* (0.42 ± 0.06%) but lower than the values obtained for *A. lobata* (2.57 ± 0.08%) and *M. morindoides* (2.46 ± 0.14%). The determination of the extractive contents was necessary because surface waxes and encrusting substances make fibre surfaces smooth and interfere with adhesion of the fibres to polymer matrices when used as reinforcement materials (Eichhorn et al., 2001; Saha et al., 1990). The extractive content of *A. lobata* is comparable to an earlier study on curaua (5.3%) using acetone as the extracting solvent (Marques et al., 2010). *Ampelocissus leonensis, C. palmitifida, and M. morindoides* had lower total extractives contents when compared with fibres from barley straw (5%) and corn stover (10%). *U. lobata* had higher total extractives content when compared with fibres from barley straw (5%), corn stover (10%). Thus, pretreatment is required before composite reinforcement with this fibre.

The determination of the moisture content of fibres is very important because fibre dimensions and properties vary with the moisture content (Mohanty et al., 2000). Such properties affected by the moisture content include

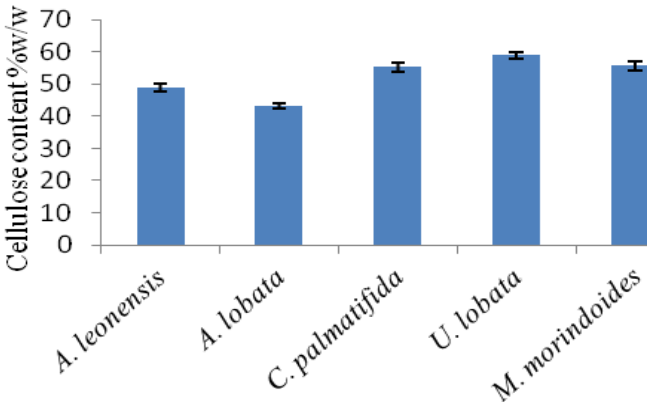

Figure 5. Cellulose contents of fibres in %w/w basis (Error bars refer to 95% JSCI).

the degree of crystallinity, crystallite orientation, tensile strength, swelling behavior and porosity (Sukumaran et al., 2001). Also, increased moisture content decreases electrical resistance and this affects the dimensional stability (Mohanty et al., 2000; Sukumaran et al., 2001). The strong hydrophilic nature of plant fibres means that precautions must be taken to improve the water-related dimensional stability of the fibres, and to enhance the low compatibility between the fibres and the hydrophobic polymeric matrix (Madsen, 2004). The moisture content of *A. lobata* in this study is comparable to that of rice straw (6.5%), abaca (5 - 10%) and hemp (6.2 - 12%) but are lower than the moisture contents of flax (8 - 12%), jute (12.5 - 13.7%) and sisal (10 - 12%), an indication that the fibre materials may not readily absorb water (Taj et al., 2007). The moisture contents of the other samples are even lower.

Ash present in lignocellulosics contains silica that has many undesirable effects (Reddy and Yang, 2005). Silica blunts cutting machinery, reduces the digestibility of straw, interferes with the pulping process by forming scales on the surface of the reactors and makes combustion more difficult (Reddy and Yang, 2005). The ash contents (%w/w) of the fibres used in this study were comparable to the bast fibres of flax and hemp (1 - 2%) but lower than jute (8%), ramie (5%) and cotton (0%) (Averous and Digabel, 2006; Mwaikambo, 2006).

Kurshner-Hoffer cellulose

The results of Kurshner - Hoffer cellulose in % w/w basis are presented in Figure 5. The cellulose contents of the woody fibres *C. palmifitida* (55.20±1.59%), *U. lobata* (58.94±1.05%) and *M. morindoides* (55.76±1.40%) are comparable to those of kenaf (45 - 57%) and abaca (56 - 63%) (Taj et al., 2007). Also, the cellulose contents of *A. leonensis* (48.97±1.33%) and *A. lobata* (43.22±0.95%) are comparable to those of coir (36 - 43%w/w), Norway spruce (49%), barley straw (43%w/w) and corn stover (33%w/w) (Majumdar and Chanda, 2001; Rowell and Han, 2000). However, the type of cellulose (amorphous or crystalline) influences the properties and applications of the fibre such that fibres with higher crystalline cellulose would be suitable for composite reinforcement while those with higher amount of the easily hydrolysable amorphous cellulose would be suitable for pulp/paper making and bioethanol production (Madsen, 2004). Woody fibres contain a higher proportion of crystalline cellulose (60 - 70%) when compared with non-woody fibres (40 - 45%) (Madsen, 2004). Thus, lower cellulose content in woody fibres when compared to non woody ones such as cereal straws used as raw materials for bioethanol production, does not mean that such fibres will not support load bearing materials. The cellulose content is critical in order to dictate the specific use of a certain fiber (Shimizu, 2001). This also is influenced by the lignin content. For instance, fibres with high cellulose and lignin content may not be suitable for pulp/paper making or in textile industries since they will require delignification and more severe pulping conditions (Omotoso and Ogunsile, 2009). However, they may be suitable for composite production (Maya and Sabu, 2008).

Hemicellulose content

Hemicellulose contents of the fibres range from 8.62±1.67% for *M. morindoides* to 21.22±0.89% for *A. leonensis* as shown in Figure 3. These values are lower when compared with biofuel producing-lignocellulosic agro wastes such as straws of barley (27 - 38%), rice (23 - 28%), and wheat (26 - 32%) (Han, 1998; Gressel and Zilberstein, 2003; Reddy and Yang, 2005). The low hemicellulose content of the plant fibres used in this study implies that their water absorbing capacity will be low since hemicelluloses is the cell wall polymer with the highest water sorption capacity (Madsen, 2004). This is responsible for the high moisture absorption of natural fibre leading to swelling and presence of voids, which results in poor mechanical properties and reduces dimensional stability of composites (Maya and Sabu, 2008). This particular property reaffirms the potentials of the plant fibres used in this study for biocomposite technology. The low water retention capacity of the fibres decreases the activities of micro organisms when used in composite reinforcement (Maya and Sabu, 2008).

Lignin content

The lignin content of the plant fibres selected for this study (estimated as Klason lignin) ranges from 22.26±0.55% for *Urena lobata* bast fibre to 33.21±2.76% for *Ampelocissus cavicaulis* (Figure 5). These values are higher when compared with non woody bast fibres of flax (2.2%), hemp (3.7 - 5.7%) and kenaf (8 - 13%) (Taj et al.,

Table 4. Result of acid soluble lignin and its derived products.

Sample	ASL (%w/w)	% w/w ASL-derived products		
		Vanillin acid λ_{230}	p-Coumaric acid λ_{308}	Ferulic acid λ_{322}
A. leonensis	1.74 ± 0.34	0.50 ± 0.12	0.65 ± 0.14	0.41 ± 0.11
A. lobata	2.17 ± 0.08	0.57 ± 0.02	0.96 ± 0.002	0.59 ± 0.08
C. palmifitida	1.43 ± 0.20	1.41 ± 0.02	0.04 ± 0.01	N.D
U. lobata	1.02 ± 0.14	0.20 ± 0.001	N.D	N.D
M. morindoides	1.37 ± 0.05	0.91 ± 0.28	N.D	N.D

Table 5. Mechanical properties of the fibres.

Sample	Diameter (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation @break (%)
A. leonensis	0.23 ± 0.02	67.65 ± 0.73	0.42 ± 0.33	8.0 ± 0.01
A. lobata	0.40 ± 0.10	588.94 ± 2.00	2.03 ± 2.20	6.75 ± 0.01
C. palmifitida	0.14 ± 0.03	1022.73 ± 2.30	20.05 ± 8.24	2.55 ± 0.23
U. lobata	0.19 ± 0.02	2587.5 ± 4.70	51.75 ± 4.90	2.5 ± 0.50
M. morindoides	0.28 ± 0.10	1201.79 ± 2.04	11.95 ± 2.78	5.03 ± 0.11

Results expressed as mean ± S.D; n = 3.

2007); but lower when compared with the woody fruit fibres of coconut (41 - 45%) (Reddy and Yang, 2005). The high lignin contents of most of the fibres seem to be disadvantageous for their use in paper, pulp and bioethanol manufacturing, as they would require higher amount of chemicals and more drastic conditions during pulping and bleaching (Marques et al., 2010). Since lignin provides fibres with compressive strength, stiffens the fibre and protects the cellulose and hemicellulose from chemical and physical damage (Saheb and Jog, 1999), the biofibres used in this study will be suitable for composite reinforcement. Acid soluble lignin (ASL) content (Table 4) was greater in *A. lobata* (2.17 ± 0.08%) but *A. leonensis*, *C. palmitifida*, and *M. morindoides* were found to be 1.74 ± 0.34, 1.43 ± 0.02, and 1.37±0.05%, respectively. ASL-derived products (vanillin, p-coumaric acid and ferulic acid) ranged between 0.50 ± 0.12% and 1.41 ± 0.02% for vanillin; 0.04 ± 0.01% and 0.96 ± 0.002% for p-coumaric acid; and ferulic acid was detected in *A.leonensis* (0.41±0.11%) and A. lobata (0.59±0.08%).

Result of mechanical properties

Tensile strength is a measure of a material's resistance to being pulled apart. Young's modulus is a measure of the material's stiffness while elongation at break is a measure of its ability to extend linearly without breaking when subjected to pulling forces. The percentage elongation obtained for *A. leonensis* and *A. lobata* are comparable to that of cotton (7.0 - 8.0%) but lower than that of coconut fruit fibre (17 - 47%) (Beakou et al., 2008). Also, the values obtained for *C. palmitifida* (2.55 ± 0.23%) and *U. lobata* (2.5±0.50%) are comparable to those of Jute (1.5 - 1.8%), flax (2.7 - 3.2%), sisal (2.0 - 2.5%) and the synthetic fibres carbon (1.4 - 1.8%) and Glass-E (2.5%) (Taj et al., 2007; Beakou et al., 2008). The tensile strength of *U. lobata* (2587.5 ± 4.70 MPa), *C. palmifitida* (1022.73±2.30 MPa), and *M. morindoides* (1201.79±2.04 MPa) are comparable to that of flax (345 - 1035 MPa) and the synthetic glass-E fibre (2000-3500 MPa) (Bledzki and Gassan, 1999). The Young's modulus of *U. lobata* (51.75±4.90 GPa) and *C. palmifitida* (20.05±8.24 GPa) are comparable to that of jute (26.5 GPa) and flax (27.6 GPa) but higher than that of cotton (5.5 - 12.6 GPa) and coir (4 - 6 GPa). In brief, the mechanical properties of most fibres used in this study are comparable to those of other biofibres already used in manufacturing and can even match those of some synthetic fibres (Table 5).

Conclusion

The results show that plant fibres used in the present study have properties that are comparable with those of common biofibres such as kenaf, hemp and flax; and even synthetic fibres. Plant fibres are renewable resources with production requiring little energy and are biodegradable. This particular property of plant fibres is attributed to the presence of their biocomponents which include cellulose, hemicellulose and lignin that possess the necessary functional groups which can enable microorganisms to degrade them with ease. When used in the production of reinforced materials such as floor tiles, gas

cylinder, hot water tank, inner panel of cars, or when delignified for use in pulp making, these fibres may not result in severe environmental consequences. This is unlike non-biodegradable synthetic fibres which usually cause skin irritation during composite manufacturing or environmental hazard when any of its products is disposed. Plant fibres have low density, so when used in the construction of car parts such as the door panels and roof may reduce fuel consumption since it would require less energy to propel a lighter object than a heavier one.

Finally, to fully exploit the potentials that composites offer, education at Universities and other Technology Institutes is required. Sufficient knowledge of materials and manufacturing processes is required. Concerning materials, one requires the knowledge to quantify properties and to use these properties in the best way. The research and development circle for composite technology shown below requires the collaborative input of Universities, local fibre industries and enterprises to develop concepts, materials and processes in the product aspect. The natural fibre composites offer benefits to the society in different aspects including economy, ecology and technology transfer.

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