FUEL CHARACTERISTICS OF SELECTED FOUR-YEAR-OLD TREES IN NIGERIA

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ABSTRACT

With the rising cost and decreasing availability of fuelwood, fossil fuels, and fossil-based chemical feedstock in the future, there is renewed interest in using renewable, plantation-grown, tropical wood biomass as an energy source or chemical feedstock. There is, however, a lack of information on the basic fuel characteristics and chemical constituents of short-rotation, juvenile, tropical wood biomass. Content of hot-water extractive, alcohol-benzene extractive, lignin, gross heat, sulfur, and ash were determined for the samples, as well as specific gravity and results of the proximate analysis (volatile matter, ash, and fixed carbon), and the ultimate analysis (C, H, N, S, O, and ash). These properties were determined on five short-rotation tree species, a tree nut-shell, and a commercial bituminous coal. Test specimens included stems of four-year-old gmelina, eucalyptus, cassia, teak, gliricidia, and nut-shells of tetracarpidium trees all grown in Nigerian fuelwood plantations near Ibadan. Based on chemical and fuel composition, most of the juvenile tropical species and the tree nut-shells could serve as a raw material for energy in fuelwood and charcoal industries, as well as for chemical industries.

Keywords: Cassia, eucalyptus, extractives, fuelwood, gliricidia, gmelina, heat content, juvenile wood, lignin, short-rotation, tetracarpidium.

INTRODUCTION

In an effort to address the decreasing supply of fuelwood from the forest, fossil fuels, and fossil-based chemical feedstocks, we are investigating the chemical and fuel values of several tropical tree species. Specifically, species that can be grown in short rotations and that are able to coppice and fix nitrogen in their root systems are under study (Chow et al. 1983a; Panshin 1950).

The chemical components of wood, a complex organic substance, profoundly influence its utilization. The components vary widely with the species and the age of the tree because wood is not a uniform substance (Browning 1973). Thus, species rich in extractive material could have a higher potential for production of certain chemicals such as polyphenols, glycosides, tannins, and carbohydrates. Species with a high carbon and hydrogen content may be suitable for charcoal or fixed carbon production and should be ideal fuelwoods for use in households and industry (Lucas 1978, 1979).

This paper reports on tests conducted to determine fuel values and basic chem-

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ical properties of the stems of four-year-old *Gmelina arborea, Eucalyptus tereticornis, Cassia siamea, Tectona grandis,* and *Gliricidia sepium,* and the nut shells of the Tetracarpidium tree. Information regarding these tropical tree species is described as follows:

Cassia siamea Lam. was introduced into Nigeria in 1889. It is inexpensive to establish if seeded directly into the plantation site. The trees coppice readily and continue to yield well for four or five rotations. They can attain a height of five meters in four years. In northern Nigeria, this species has been used to reclaim abandoned tin-mining sites (Ola-Adams 1976). As much as 136,100 kilograms of dry wood can be obtained in ten years.

Gliricidia sepium (Jacq.) Stand. is a fast-growing tree native to Central America. It is favored for fences and boundaries all over the world. It fixes nitrogen efficiently and this facilitates its growth and its enrichment of poor soils. It serves as shade and a wind-barrier in plantations of cocoa and coffee. In Nigeria, the trees provide nutrients and soil stabilization when intercropped with cassava, maize, cucurbits, and other crops. It is a common fuelwood for curing tobacco in the Philippines (NFTA 1984). A six-year-old stand can yield up to about 34 tons per hectare.

Gmelina arborea Roxb. was introduced into Nigeria as a fuelwood plantation species in 1929. It is now the most important pulpwood species in the area. Most of the work done on gmelina in Nigeria has involved its silvicultural, pulping, and timber properties related to its use in construction. Gmelina is an especially promising crop in humid lowlands because it can be established easily and more cheaply than other species, and it regenerates well from both sprouts and seed. Coppice rotations usually occur at five-year intervals (NAS 1983). It yields three to six cubic meters of dry wood per hectare per year in Oyo and Kano States, Nigeria.

Eucalyptus tereticornis Sm. was introduced into Nigeria around 1916, and it has been raised in plantations within both the rain forest and the arid zones in the northernmost parts of the country. It promises to supply poles and construction timbers, while the standing trees are excellent for windbreaks. It grows rapidly, can withstand flooding for short periods, coppices vigorously, is one of the principal eucalyptus grown as fuelwood, and also makes good charcoal (Ojo 1970). In the Savannah areas of Nigeria, eucalyptus wood is a major fuelwood species.

Tectona grandis Linn. F. was established as fuelwood plantation material in Ogun, state of Nigeria, in 1911. Although teak has been an important timber species in furniture manufacture and construction material uses, it is still being raised in fuelwood plantations in the rain forest areas of Nigeria (FPRL 1965). It yields about 28 cubic meters of fuelwood per hectare per year in Southwestern Nigeria.

The *Tetracarpidium conoiphorum* tree is indigenous to southern parts of Nigeria, where it is cultivated for its edible, oil-rich fruit. The creamy-white seed is encased in a brown shell. The cooked seeds are available on the open market, so a large quantity of seed shell is available daily in Nigeria, which could be a viable raw material for utilization (Hutchinson and Dalziel 1958). The seeds are called "walnut" by the local people.

Most of the research work done on the above six species has involved silviculture, pulping, and timber properties (Lucas 1978). Little information is available on the chemical composition and energy properties of these species. This type of information is needed for determining the physical and chemical constituents of short-rotation, fast-growing juvenile trees. The industry can then critically examine future sources of chemical feedstock, energy, and fibers.

MATERIALS

Four randomly selected stems of gmelina, cassia, teak, eucalyptus, and gliricidia were obtained fresh from a fuelwood plantation in Ibadan, Nigeria. The materials harvested in the fall of 1982 were all four-year-old trees. The seed-shells of the Yoruba tree (*Tetracarpidium conoiphorum*) were also collected from the Ibadan area. All the sampling trees were conditioned to room temperature (20 ± 3 C, 65% RH) in a forced-air circulation oven for one week before preparation.

The stems with bark and the seed shells were reduced to particles by passing them through a 40-mesh or 60-mesh screen in a Wiley mill. Stems of the same species were combined to create a composite sample. All the ground materials were oven-dried at 105 C. A commercial bituminous coal sample obtained from the Illinois Power Company, Oakwood, Illinois was also ground and oven-dried.

TEST METHODS AND ANALYSIS

All analyses and procedures followed the methods described in the standards of the American Society for Testing and Materials (ASTM 1982; Chow et al. 1983a). The contents of ash, lignin, alcohol-benzene, hot water, gross heat, and sulfur of all wood specimens were determined using methods described in ASTM designation: D1102, D1106, D1107, D1110, D2015, and D3177, respectively.

The proximate and ultimate analyses were conducted on specimens according to test methods described in ASTM designation: D3172 and D3176 (ASTM 1982).

The analysis of variance was conducted to determine the effect of wood species on chemical properties. Duncan's multiple-range procedure for detecting the difference between each material was also used.

RESULTS AND DISCUSSION

Table 1 shows the stem size, specific gravity at oven-dry moisture level, two extractive contents, lignin content, gross heat value, and sulfur and ash content of each species and sample material. Table 2 shows the test results of both the proximate and ultimate analyses of all specimens. The published literature values for the commercial coal are also provided in both tables. Each value listed in the tables is an average of six tests, each conducted on the composite sample of each species. Measurements of the chemical and fuelwood properties of the test samples indicated that there were no significant variations between replicates in any analysis of the six replicates. The results of the analysis of variance indicated that species type significantly affected all of the physical and chemical compositions of the four-year-old juvenile trees at 5% level. The results of Duncan's multiple-range analysis are discussed in the following paragraphs.

Specific gravity

The specific gravity of five stem-woods ranged between 0.45 and 0.70. Gliricidia and gmelina had the highest and lowest density, respectively. The specific gravity

TABLE 1. *Some chemical and energy properties of four-year-old short rotation fuelwoods.*[1]

Materials	Diameter (cm)	Specific gravity[2]	Extraction or solubility (%) Hot-water	Alcohol-benzene	Lignin (%)	Oxygen bomb Gross heat (cal/g)	Sulfur (%)	Ash (%)
Gmelina arborea (stem)	7	0.45 (3.7)[3]	4.4 (3.6)	7.3 (1.2)	26.1 (2.5)	4,290 (0.3)	0.12 (2.5)	2.5 (4.1)
Eucalyptus tereticornis (stem)	7	0.59 (2.6)	6.7 (3.8)	5.0 (0.6)	30.4 (2.1)	4,050 (0.4)	0.13 (3.1)	6.8 (3.6)
Cassia siamea (stem)	8	0.67 (5.1)	5.8 (2.3)	6.9 (0.5)	28.3 (1.8)	4,210 (0.3)	0.10 (2.9)	3.5 (4.0)
Tectona grandis (stem)	8	0.62 (2.6)	3.5 (1.6)	9.5 (0.5)	19.8 (1.3)	4,580 (0.2)	0.14 (4.8)	7.5 (2.4)
Gliricidia sepium (stem)	5	0.70 (1.7)	5.0 (2.3)	5.4 (4.0)	23.1 (1.4)	4,250 (0.1)	0.22 (5.0)	1.8 (1.8)
Tetracarpidium conoiphorum (nut-shell)	—	0.85 (0.8)	5.1 (2.4)	5.1 (2.8)	35.2 (2.6)	4,930 (0.2)	0.19 (3.5)	1.6 (0.8)
Bitmuminous coal:								
a) Illinois	—	1.25 (2.4)	—	—	—	7,350 (0.5)	3.45 (5.0)	10.5 (2.4)
b) Published[4]		1–2	—	—	—	5,233–7,760	1–5	8–12

[1] Each value is an average for six tests.
[2] Based on oven-dry weight and air dry volume.
[3] Coefficient of variation, CV (%) = Standard Deviation/Average × 100.
[4] (FPRS, 1977).

did vary significantly among different species and materials. On the same volume basis, the coal weighed twice as much as the juvenile trees, and the nut-shells of the tetracarpidium tree contained more solid material than the stems of five species. It is well known that specific gravity, or density, is the most important physical property affecting the characteristics of wood burned for fuel.

Extractive

The hot-water extractive contents of six species, including the nut-shells in this study, averaged from 3.5% (teak) to 6.7% (eucalyptus). These values are much higher than the reported average value (2%) of the North American hardwood species (Brown et al. 1952). However, 7 to 12% of hot-water extractives, and 3 to 6% of alcohol-benzene extractive values were obtained from Mozambique teak wood reported by Petterson (1984). Hot-water extractives are principally comprised of inorganic salts, oligosacharides, sugars, cycloses, and cyclitols. An average value for alcohol-benzene extractive content of commercial hardwood was reported to be 2% (Chow et al. 1983a). The average value obtained in this study ranged from 5% (eucalyptus) to 9.5% (teak). Both gmelina and cassia stems contained more than 6% of the alcohol-benzene extractive content, which consisted of certain phenolic substances such as sterols and tannins, some organic acids such as resin acid and amino acid, and some pigment materials. According to Duncan's statistical analysis, there is no significant difference between the value obtained from the gliricidia stem and the tetracarpidium nut-shell.

TABLE 2. *Comparative fuel analysis of plantation-grown fuelwoods, nut-shell, and commercial coal (dry basis, percent by weight).*[1]

Materials	Proximate analysis: Volatile matter	Proximate analysis: Ash	Proximate analysis: Fixed carbon	Ultimate analysis: Carbon	Ultimate analysis: Hydrogen	Ultimate analysis: Nitrogen	Ultimate analysis: Oxygen	Ultimate analysis: Sulfur	Ultimate analysis: Ash
Gmelina arborea	78.0	4.5	17.5	48.4	6.7	0.2	40.7	0.1	3.9
(stem)	(0.2)[2]	(0.2)	(0.5)	(2.2)	(1.1)	(0.2)	(1.2)	(0.3)	(3.1)
Eucalyptus tereticornis	76.7	6.0	17.3	43.7	5.7	0.2	44.9	0.1	4.4
(stem)	(1.2)	(0.3)	(0.4)	(3.0)	(2.5)	(0.1)	(1.1)	(0.3)	(4.0)
Cassia siamea	78.3	4.0	17.7	49.8	6.6	0.4	38.7	0.1	4.4
(stem)	(0.1)	(0.3)	(1.5)	(1.5)	(3.2)	(0.3)	(0.5)	(1.2)	(3.3)
Tectona grandis	74.7	8.7	16.6	47.2	6.4	0.4	36.6	0.2	9.2
(stem)	(1.4)	(0.4)	(3.1)	(3.5)	(1.6)	(0.2)	(0.6)	(1.1)	(2.5)
Gliricidia sepium	83.6	1.5	14.9	44.8	6.8	0.3	46.6	0.2	1.3
(stem)	(1.0)	(0.5)	(0.5)	(1.6)	(1.5)	(0.1)	(2.2)	(2.1)	(3.7)
Tetracarpidium conoiphorum	67.4	2.2	30.4	52.1	6.1	0.5	39.1	0.2	2.0
(nut-shell)	(0.2)	(0.1)	(2.1)	(2.0)	(1.0)	(0.5)	(3.1)	(2.4)	(4.5)
Bituminous coal:									
a) Illinois	45.6	9.7	44.7	73.2	4.9	1.2	6.8	3.5	10.4
	(1.5)	(1.3)	(0.5)	(3.0)	(1.8)	(0.6)	(4.1)	(1.2)	(5.0)
b) Published[3]	36–44	5–10	51–57	54–78	5–7	1–2	7–34	1–5	8–12

[1] Each value is an average for six tests.
[2] Coefficient of variation (%) = Standard Deviation/Average × 100.
[3] (FPRS, 1977.)

Lignin

The lignin content varied significantly among all species. The nut-shell was found to have the highest lignin content (35%) in this study. The teak stem obtained the lowest value (20%) of lignin content. The basic structure of lignin includes aromatic rings, propane, and methoxyl and hydroxyl groups. Lignin can be made into products such as vanillin, adhesive extenders, binders, tanning agents, and solid fuel (Panshin et al. 1950). Petterson (1984) reported that the Mexican eucalyptus, Ghanian gmelina, and Taiwanese cassia had a lignin content of 22, 29, and 25%, respectively.

Gross heat value

The average gross heat value ranged from 4,040 cal/g for eucalyptus, to 4,580 cal/g for teak, in four-year-old species; and was 4,930 cal/g for the nut-shell of the tetracarpidium tree. However, coal had a greater heat value than any of the other materials tested in this study. By direct combustion, about 1.7 tons of dry, four-year-old teak, gmelina, gliricidia, cassia, or eucalyptus trees yielded about the same amount of heat as 1 ton of commercial grade coal. The data also indicate that teak had the highest gross heat content. The high gross heat of combustion could be attributed to the fact that teak possesses the highest content of alcohol-benzene extractives in this study. Howard (1973) reported that alcohol-benzene extractive content was positively correlated with the heat content of southern pine.

Ash content

Except the eucalyptus and cassia in the ultimate analysis, the ash content was significantly affected by the species. The average ash content of five four-year-old juvenile tree stems was much higher than that of the North American commercial hardwood species, reported value of six two-year-old juvenile wood stems, and tropical wood species (0.5–2.1% ash) (Chow et al. 1983a, b; Petterson 1984). The ash content for both teak and eucalyptus was more than 6%, while the commercial coal had 10% ash. This higher ash content could be explained by the fact that these juvenile tropical wood species need more mineral substances for growth than do other woods. The young tropical trees would, therefore, absorb more mineral material from the soil and store it in cell walls and cell cavities. When wood is used as a fuel, the accumulation of ash will interfere with combustion and reduce the efficiency of the furnace. In general, ash content is an unfavorable factor that needs to be controlled during the direct combustion of wood.

Proximate analysis (volatile matter and fixed carbon content)

Gliricidia stems and coal had the highest and the lowest volatile matter content, respectively. The nut-shell had the second lowest volatile content among the seven materials tested. Regarding the five juvenile wood stems, the average values ranged from 74.7% for teak to 83.6% for gliricidia. Both the cassia and gmelina obtained the same value of volatile content. The average values of fixed carbon content obtained from the stem of cassia, gmelina, and eucalyptus were statistically the same. The results of the proximate analysis indicate the percent of volatile matter and fixed carbon content that may be used to establish burning characteristics of a solid fuel during combustion and gasification in a furnace. The results of the fixed carbon content show that the nut-shell of tetracarpidium should be a viable raw material for charcoal production.

Ultimate analysis (C, H, N, S, O)

The bituminous coal had the highest percent values of carbon, nitrogen, sulfur, and ash in this element analysis, while the nut-shell ranked second in carbon content. The results of Duncan's multiple-range test show that the average carbon content varies significantly at the 5% level among all species and materials. All four-year-old tropical juvenile woods and the nut-shell possessed about 60% of the carbon content of coal, 6.5% hydrogen, and 40% oxygen content, and a small amount of sulfur and nitrogen, both of which are considered pollutants in fuel. These tests agree with the results reported on sulfur and nitrogen content in North American woods (FPRS 1977). It is clear that the results of this analysis can be used to calculate the chemical balances needed to support combustion as well as air, including oxygen required for burning a fuel, and the quantity of potential pollutants.

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