Evaluation of selected biomass for charcoal production

P Sugumaran and S Seshadri*

Shri AMM Murugappa Chettiar Research Centre (MCRC), Taramani, Chennai 600 113, India

Casuarina equisetifolia L. and *Lantana camara* L. leaf litter, sugarcane bagasse and empty oil palm fruit bunch (*Elaeis guineensis* Jacq.) were converted into charcoal using carbonization process. An increase in temperature from 200°C to 400°C decreased charcoal yield gradually in all samples. Energy content in fresh biomass was lower than pyrolysed charcoal. Calorific value of fresh biomass and pyrolysed charcoal, respectively, was maximum in *C. equisetifolia* L. leaf litter (18.48 MJ/kg and 29.89 MJ/kg) and minimum in oil palm fruit bunch (16.96MJ/kg & 18.46MJ/kg).

Keywords: Biomass**,** Carbonization**,** Calorific value, Charcoal**,** Pyrolysis

Introduction

Biomass, fourth largest energy source in the world, provides about 13% of world's energy consumption[1]. Globally[2], biomass has an annual primary production of 220 billion oven-dry tonnes (odt) or 4,500 EJ and India[3] produces 350 million tonnes of agricultural wastes per year. Charcoal is a premium fuel widely used in many developing countries to meet household as well as a variety of other needs[4,5]. Recent improvements in technology for charcoal production have increased its efficiency[6-8], resulting in renewed interest in the use of charcoal as a fuel that can be easily stored and transported. High-value carbon products (activated carbon and electrode carbon) can also be produced from charcoal. This study presents charcoal production from *Casuarina equisetifolia* L. and *Lantana camara* L. leaf litter, sugarcane bagasse and empty oil palm fruit bunches (*Elaeis guineensis* Jacq.).

Materials and Methods

Samples collected were: 1) *C. equisetifolia* L. and *L. camera* L. leaf litter from Thiruvidanthai village, Kanchipuram District, Tamilnadu, India; 2) sugarcane bagasse from M/s EID Parry (P) Ltd., Nellikuppam, Tamilnadu, India; and 3) oil palm fruit bunch (*E.* *guineensis Jacq.)* from M/s Cauvery palm Oil Limited, Varanavasi, Tamilnadu, India.

Chemical Analysis

Cellulose, hemi-cellulose and lignin content of dry biomass were determined by reported methods[9]. Moisture, ash, volatile matter and fixed carbon of air-dried biomass (particle size 1.8 mm) were determined by standard procedures[10]. Bulk density was determined by reported method[11]. Elemental analysis of air-dried biomass samples was performed using CHNS-O Elemental Analyzer (Perkin-Elmer 2400 Series). Samples were ground to fine powder and each agro waste (1 mg, dry basis) was weighed on tin foil and placed into elemental furnace and subjected to complete combustion in a pure oxygen environment. For oxygen content analysis, sample (1 mg) was placed inside a silver capsule and placed into furnace and heated at 1000°C. After complete combustion, samples were screened using infrared detector to determine oxygen content.

Pyrolysis

Preweighed dry biomass of all substrates packed in metal boxes (15 cm x 15 cm x 5 cm; LBH) having two holes (diam, 2.54 cm) and covered with a lid, were subjected to pyrolysis in a muffle furnace at different temperatures (200, 250, 300, 350 and 400°C) for 30 min. After pyrolysis, cooled samples were weighed and charcoal yield was calculated as

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*Author for correspondence
Tel.: +91 44 22430937; fax: +91 44 22430369.
E-mail: energy@mcrc.murugappa.org

Table 1—Proximate analysis of biomass samples

Sample name	Moisture %	Volatile matter %	Fixed carbon %	Ash %	Bulk density kg/M³
C. equisetifolia leaf litter	5.40 ± 0.60[a]	73.50 ± 5.96[a]	16.46 ± 0.70[c]	3.93 ± 0.80[a]	195.19 ± 0.89[a]
L. camara leaf litter	8.06 ± 0.85[bc]	70.46 ± 0.80[a]	11.83 ± 1.00[b]	7.26 ± 0.55[b]	210.24 ± 2.09[c]
Sugarcane bagasse	8.87 ± 0.68[c]	85.06 ± 1.32[b]	6.66 ± 0.51[a]	4.33 ± 1.02[a]	200.78 ± 0.25[b]
Oil palm fruit bunch	6.36 ± 0.75[ab]	78.20 ± 1.21[ab]	16.46 ± 0.70[c]	4.53 ± 0.60[a]	280.11 ± 1.39[d]

Values are mean ± standard deviation of three replicates; Means followed by same letter within each column do not differ significantly (Tukey test) at 5% level.

Table 2—Ultimate analysis of biomass samples

Sample name	Carbon %	Hydrogen %	Nitrogen %	Oxygen %
C. equisetifolia leaf litter	46.12	6.90	1.18	42.64
L. camara leaf litter	45.01	6.68	2.02	43.79
Sugar cane bagasse	44.60	6.20	0.20	46.84
Oil palm fruit bunch	45.90	5.80	1.20	40.10

Results based on one time analysis

Table 3—Biochemical properties of biomass samples

Sample name	Cellulose, %	Hemicellulose, %	Lignin, %
C. equisetifolia leaf litter	30.83 ± 2.25[a]	25.76 ± 1 .10[c]	18.24 ± 1.15[b]
L. camara leaf litter	33.53 ± 2.02[a]	22.14 ± 0.74[b]	16.22 ± 1.05[b]
Sugar cane bagasse	33.29 ± 1.43[a]	26.76 ± 0.71[c]	12.63 ± 1.03[a]
Oil palm fruit bunch	58.07 ± 1.69[b]	2.06 ± 0.84[a]	26.87 ± 1.59[c]

Values are mean ± standard deviation of three replicates; Means followed by same letter within each column do not differ significantly (Tukey test) at 5% level.

Charcoal yield (%) = A/B x 100   …(1)

where A is weight of charcoal after pyrolysis and B fresh biomass before pyrolysis.

Calorific Value (CV) Analysis

CV of dried biomass and carbonized charcoal powder was determined by pelletizing samples (1 g) and burning inside an oxygen bomb calorimeter (Rajdhani-RSB Digital Bomb Calorimeter, India) under adiabatic conditions. CV was calculated according to Indian standards (IS-1350-1966), British standards (BS-1016, 1967) and Institute of Petroleum (IP-12/63 T) standard test methods.

Results and Discussion
Biomass Analysis

Data on proximate (Table 1) and elemental analysis (Table 2) of four samples were recorded. Fixed carbon was high in *C. equisetifolia* leaf litter (16.47%) and oil palm fruit bunch (16.46%), followed by *L. camara*

(11.83%) and sugarcane bagasse (6.66%). Ash content of samples was in the order: *L. camara* (7.26%) > Oil palm fruit bunch (4.53%) > sugarcane bagasse (4.33%) > *C. equisetifolia* leaf litter (3.93%). High bulk density was observed in oil palm fruit bunch (280.11 kg/m³) followed by *L. camara* (210.24 kg/m³) sugarcane bagasse (200.78 kg/m³) and *Casuarina* leaf litter (195.19 kg/m³). Elemental analysis showed that all biomass samples contained almost equal amount of carbon (C), hydrogen (H), and oxygen (O) with some variations in nitrogen (N) content. All samples recorded higher cellulose and lignin compared to hemicellulose. However, oil palm fruit bunch sample recorded high cellulose and lignin content and low hemicellulose content (Table 3).

Variations in Charcoal Yield

Charcoal yield was inversely proportional to temperature in all samples (Fig. 1). Maximum charcoal yield was recorded at 200°C in *C. equisetifolia leaf* litter (52.14%) followed by *L. camara.* (45.33%), oil palm fruit bunch (44.52%) and sugarcane bagasse (34.66%).
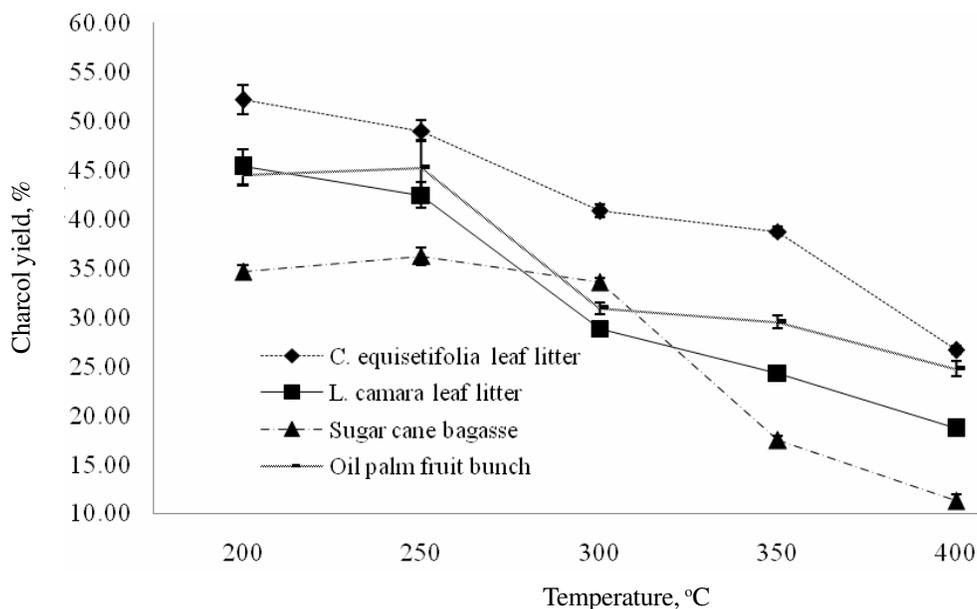
Fig. 1—Different temperature on charcoal yield

At 250°C, oil palm fruit bunch and sugarcane bagasse recorded higher char yield. *C. equisetifolia* leaf litter produced higher charcoal yield in all temperature regimes than other samples tested. Lower charcoal yield recorded in sugarcane bagasse could be attributed both, to substrate quality where fine pith particles in bagasse would be converted to ash immediately after exposure to high temperatures, and to its low fixed carbon content (Table 1). *C. equisetifolia* leaf litter and oil palm fruit bunch samples, respectively, recorded highest charcoal yield and carbon content (46.12 and 45.90%) and lower amount of oxygen (42.64 and 40.10%) and volatile compounds (73.50 & 78.20%) compared to other samples.

Calorific Value (CV)

CV or higher heating value (HHV) of dried biomass and carbonized charcoal (Table 4) indicated that CV of *C. equisetifolia* leaf litter (161%) and sugarcane bagasse (142%) were higher in carbonized charcoal than dried biomass; values were less in *L. camara* (115%) and oil palm fruit bunches (108%). *C. equisetifolia* leaf litter had highest calorific value for both dried biomass (18.48 MJ/kg) and carbonized charcoal (29.89 MJ/kg).

Discussion

Cellulose, hemicellulose, lignin, lipids, organic acids and minerals comprise over 90-95% of biomass in a plant[12,13]. Carbonization of lignocellulosic materials involves depolymerization, cracking and dehydration of lignin and cellulose in biomass[14,15]. During biomass conversion at low temperatures, cellulose is converted to anhydrocellulose. At high temperature, cellulose gets depolymerized and produces levoglucosan. Anhydrocellulose yields better charcoal than levogluscosan[16-18]. Though charcoal yield do not have direct relationship with fresh weight of sample, some good relationships between lignin and cellulose content in samples have been reported[19-25]. This study shows that charcoal yields differ according to biomass characteristics and temperature used in carbonization process. Charcoal yield also decreased when temperature was increased.

Demirbas[19,20] reported that CV of renewable natural fuel can be calculated by using C (wt%), H (wt%) and O (wt%). In present study, char produced from *C. equisetifolia* leaf litter showed higher CV (28.89 MJ/Kg) than fresh biomass samples. After carbonization, biomass CV increased two fold, could be due to volatile matter, ash and fixed carbon in biomass and also to their C, H, and O content.

In present study, *C. equisetifolia* leaf litter and oil palm fruit bunch samples, respectively, recorded highest charcoal yield and carbon content (46.12 & 45.90%) and lower amount of oxygen (42.64 & 40.10%) and volatile compounds (73.51 &78.20%) compared to other biomass samples. Results of this study are in consonance with earlier reports[26-29] where presence of carbon and coke forming components such as lignin at higher quantities and O, H, H/C ratio and volatile components

Table 4—Calorific value of dry biomass and carbonized char

Sample name	Dry biomass MJ/kg	Carbonized char MJ/kg	Calorific values %
C. equisetifolia leaf litter	18.48 ± 0.66[ab]	29.89 ±1.00[c]	161.0
L. camara leaf litter	18.50 ± 1.03[b]	21.42 ± 1.12[b]	115.0
Sugar cane bagasse	16.46 ± 0.63[a]	23.43 ± 1.00[b]	142.0
Oil palm fruit bunch	16.96 ± 0.72[ab]	18.46 ± 0.62[a]	108.0

Values are mean ± standard deviation of three replicates; Means followed by same letter within each column do not differ significantly (Tukey test) at 5% level.

at lower concentration are reported to result in higher charcoal yields.

Conclusions

C. equisetifolia leaf litter could be effectively carbonized at 200°C to obtain highest charcoal yield followed by *L. camara,* oil palm fruit bunch and sugarcane bagasse.

Acknowledgements

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