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Sustainable bio-energy potential of perennial energy grass from reclaimed coalmine spoil (marginal sites) of India

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ABSTRACT

Usage of marginal lands to grow perennial grass for biomass feedstocks is a promising option to meet the bioenergy demand in India. In this context, the present work investigated the potential utility of two perennial grass species *Cenchrus ciliaris* (L.) and *Pennisetum pedicellatum* (Tan.) to be a new promising energy source for bioenergy. This study entails a detailed characterization of biomass feedstocks using proximate and ultimate analysis, and lignocellulosic fractions and thermogravimetric behaviour using TG-FTIR and Py-GC/MS spectrophotometry to evaluate their potential as an alternate green fuel to fossil fuels by measuring their thermochemical conversion functioning. Property analysis of perennial grass species showed a significant difference in moisture content (7.2–8.5%), volatile matters (80.5–82.4%), fixed carbon (11.3–18.9%), HHV (15–17.8 MJ/kg) and LHV (14.3–16.5 MJ/kg), which is very promising for bioenergy generation. Lignocellulosic fractions of biomass feedstocks are comparable to the previous studied biomass species including switchgrass and elephant grass. The individual decomposition experiments indicated that biomass feedstocks possess higher thermochemical reactivity and shorter devolatilization time. According to Py-GC/MS study, carbonyl compounds including aldehyde and ketones are the major volatile products, in addition to furans, benzenes, phenols, acids, and others. The TG-FTIR results showed that main gaseous products evolved during devolatilization are CO, CO_2, CH_4, and H_2O. All of the results and findings would help in characterizing the biomass as potential bioenergy feedstocks compatible with other biomass currently in use as supplementary fuel for power generation.

1. Introduction

Globally, the energy sector faces a major challenge of providing energy at an affordable cost without adversely affecting the environment [1]. Almost one-quarter of world human populations are living under deficient basic energy demands that are not being met. Efforts to increase renewable energy resources in developing countries where per capita energy availability is low are needed [2]. Therefore, in recent years production of alternate energy, fuels and a variety of chemicals from lignocellulosic biomass has attracted scientific attention worldwide [3]. In this context, renewable bioenergy feedstocks act as a promising alternative resource to provide about 14% of the world's energy demand [4]. Moreover, lignocellulosic biomass mainly includes agricultural residue, wood waste, energy crops, noted energy grass species (switchgrass, miscanthus, napier grass), and aquatic plants. Therefore, they are considered as a potential resource for meeting bioenergy demands [5]. Bioenergy can be readily converted to produce heat and electricity, and production of biofuels. As a sustainable energy sources, bioenergy feedstocks are widely available and receiving increased attention as a renewable substitute for fossil fuels. Conversely, if produced sustainably and used efficiently, it will reduce oil demand, addressed major environmental problems, and it can induce economic growth in a developing country. Other major prospective benefits of bioenergy cultivation include restoration of soil productivity of degraded land, improving access to quality of energy services, and reduction of major greenhouse gas emission [6].

In India, a number of different species variety of perennial grasses are available throughout the year which often grows in wild conditions and characterized as low input-high yielding biomass. Therefore, these energies grasses can be act as a potential resource for bioenergy feedstock without adversely affecting the soil C stocks [6]. Accordingly, the different varieties of perennial grasses (switchgrass, bermudagrass, elephantgrass, timothygrass) and

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lignocellulosic biomass (wheat straw and pinewood) would be used for the thermochemical conversion (pyrolysis) process [7]. However, the availability of land to grow energy crops is the primary concern for the development of such bioenergy resources. Recently, several studies have found that the marginal lands should be used for sustainable production of biomass feedstocks (bioenergy crops) based on the profitability of current land use, soil health, and environmental degradation indicators [8]. Cai et al. [9] estimated that around 1107–1411 Mha of degraded land available globally for energy crop production constitute up to 26–55% of the world energy from biomass [9,10], and the energy crop yields on such soils were estimated to vary from 1 to 10 t ha^{-1} yr^{-1}. Likewise, open cast mining activities degrade 2–10 times more land as compared to underground mining [11], which leaves a landscape with no vegetation with adverse effects on the soil erosion, water, and air pollution. Therefore, utilization of such degraded lands for cultivating bioenergy feedstocks is an efficient way to conserve natural resources, such as lowered soil erosion and run-off, enhanced soil C-sequestration, and yielding biomass for thermochemical conversion while contributing to domestic energy demand [12]. This may be main reason why there is increasing trend in this research area.

Recently pyrolysis of biomass has received strong interest due to limited availability of fossil resources. In addition, pyrolysis is a simple thermochemical process to transform lignocellulosic into low-molecular-weight compounds. Provided, the yield and composition of pyrolysis products strongly depend on the sources and quality of the biomass feedstocks as well as on the process parameters [13]. However, several new analytical techniques were developed to measure the degradation process as well as the composition of the products. In thermochemical conversions, the forestry and wood species were mainly used as reference feedstocks, while herbaceous perennial grass biomass has received little attentions. The woody biomasses are characterized with high C/N ratio, low ash content, and their ash contains low mineral constituent avoiding slagging, fouling, and less corrosion to the instruments [14]. Further, they possess a higher heating values and biomass density on one hand, and increasing energy conversion efficiency on the other hand. However, woody species showed relatively less importance due to limited land availability than many herbaceous perennial grasses, and their annual biomass yield is generally lower due to slow growth rate in the post-establishment years [15]. In addition, the harvest is also quite major problem because its required more energy for biomass comminution due to greater biomass recalcitrant [15]. Therefore, further research on low cost production biomass feedstocks required for energy production. Accordingly, we have selected two perennial grasses species namely *Cenchrus ciliaris* (L.) and *Pennisetum pedicellatum* (Tan.) mainly used for reclamation in coalmine degraded landscapes in Jharia Coalfield, India, with the aim to estimated their bioenergy potential.

Cenchrus ciliaris (L.) and *Pennisetum pedicellatum* (Tan.) species are two perennial grass species which is widely adapted to degraded soils with poor in water content and nutrients availability, and can grow upto a height of 0.5–1.2 m. Both the genus contains several species, most of them is considered as commercial biological resources due to low cost production, adaptation in poor soils, and grows on limited water requirement. Thus, due to its abundance and low cost to grow on degraded landscape, the perennial energy grasses was selected for thermochemical conversions for the first time from mine degraded lands in India. The proximate and ultimate and thermochemical conversion behaviors (TG-FTIR-GC/MS) shown that both the perennial grass species has pyrolysis and energy properties compare to other traditional energy grasses including miscanthus and switch grass.

2. Materials and methods

2.1. Study area and sample collections

The study was carried out in an ecologically restored coalmine overburden dumps located in the Damoda colliery, Barora area, BCCL (Bharat Coking Coal Limited), Jharia Coalfields, Jharkhand, India. The Jharia coalfields fall between latitudes 23° 39′–23° 48′ N and longitudes 86° 11' – 86° 27′ E covering an area of 450 km^2 (Suppl. Fig. 1). The total study area was approximately 4 ha (40, 000 m^2) and the age of the entire restored site is 4 years. The climate of the study area is dry tropical, having hot and dry summer season (March to June), followed by wet season (July to September) and winter season (November to February). However, the area receives an annual rainfall of about 1140–1700 mm with an average annual relative humidity of about 68%. Mine spoils were afforested with grass-legume mixtures before the onset of monsoon (May–June 2014) through social forestry program, BCCL, India. Upon maturation, the biomass samples of two most dominant grass species *Pennisetum pedicellatum* (Tan.) and *Cenchrus ciliaris* (L.) collected during winter seasons i.e. January 2015. Although, the grass species were selected on the basis of their capacity to produce biomass annually. The dry matter yield of *Pennisetum pedicellatum* is 7.5–8 t ha^{-1} yr^{-1} and for *Cenchrus ciliaris* is 4–8 t ha^{-1} yr^{-1}, respectively. The biomass samples were air dried, grinded and sieved using a Wiley mill to produce particle size <2.5 mm, according to ASTM E828-81 protocol.

2.2. Methods

To correlate the respective composition with the thermal behavior of the biomass feedstocks, chemical and physical analysis was performed.

2.2.1. Proximate and ultimate analyses

The proximate analysis was performed for the determination of moisture, ash and fixed carbon content and volatile matter following the ASTM standardized procedures. The measurement was done for moisture content using ASTM E871-82, volatile matter following ASTM E872-82, ash content according to ASTM E1755-01. This process allows removal of volatile and fixed carbon content. Fixed carbon content was measured as according to [16].

$$\% \, FC = 100 \, (\% \, Ash - \% \, VM) \quad (1)$$

The ultimate analysis was performed to determine the basic elemental composition of biomass. The carbon (C), nitrogen (N), hydrogen (H), and sulfur (S) content of the samples were measured in the Perkin-Elmer CHN 2400 elemental analyzers at Organic Chemistry Laboratory, Indian Institute of Science (IISc) Bangalore, India. The samples were burnt in a pure oxygen atmosphere and the combustion gases were automatically measured. The oxygen content was determined by subtracting the sum of the other element contents from 100%.

2.2.2. Higher heating value

The higher heating value (HHV) of the biomass feedstocks were estimated in a static and adiabatic bomb calorimeter, Parr 1241, according to the ASTM D2015 for determination of the gross calorific value [17]. Biomass feedstocks were grounded to obtain a homogeneous fine powdered sample. These powder samples were well mixed and dried at 105 °C for 6 h and stored in a desiccator for a period of 12 h. Finally, the powder samples were pressed in the form of pellets of 1 cm in diameter with a mass content of approximately 0.5 g. The combustion of samples was done in the