



Thermochemical characterization of banana leaves as a potential energy source



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ABSTRACT

Wet and semi-dried banana leaves were characterized through elemental and proximate analyses, lignocellulosic fraction and thermogravimetric analysis (TG/DTG), differential scanning calorimetry (DSC) and high heating value analysis to assess their use as biomass in generating energy through combustion; they were also assessed to determine the potential of obtaining value-added products through pyrolysis. The wet banana leaves had high moisture content of 74.7%. The semi-dried samples exhibited 8.3% moisture, 78.8% volatile solids, 43.5% carbon and a higher heating value of 19.8 MJ/kg. The nitrogen and sulfur contents in the banana leaves were very low. The semi-dried and wet leaves had hemicellulose and lignin contents close to other biomass fuels, and the semi-dried leaves had the lowest cellulose content, of 26.7%. The wet and semi-dried samples showed the same thermal events in oxidizing and inert atmospheres, but with distinctly different mass loss and energy release intensities. The chemical characteristics and the thermal behavior demonstrated by the semi-dried samples indicate their potential for use as biomass, with results similar to other agro-industrial wastes currently used.

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1. Introduction

In Brazil, the banana plant is grown in all states of the country. Data released by the Center of Socioeconomics and Agricultural Planning for the State of Santa Catarina [1], show that in 2009, Santa Catarina was responsible for 8.7% of the Brazilian banana production. The state produced 7.2 million-tons of bananas, mainly the *Musa sapientum* and *Musa cavendishii* species, these are commonly known in the region as white banana and “nanica” banana, respectively.

In banana culture, vast quantities of wastes including the skin, leaf, pseudostem and stalk are generated. For every ton of bananas plant picked, 100 kg of fruit is rejected and approximately 4 tons of lignocellulosic wastes (3 tons pseudostem, 160 kg stalks, 480 kg leaves and 440 kg skins) are generated. With the exception of a part of the banana skins normally fed to pigs, these wastes are spread over the fields and left to decompose naturally. Using these wastes for the production of inputs or transforming them into a true commodity would reduce environmental pollution and add value to banana cultivation, which has suffered in recent years due to the fluctuation of the product price on the domestic market.

Agro-industrial wastes are increasingly being used as biomass for generating energy and inputs such as sugar cane bagasse, wood briquettes, rice husk, straw and corncobs from thermochemical

conversion; these conversion process include liquefaction, gasification, pyrolysis and combustion [2–4].

Generally, using biomass as a primary source to produce thermal and electric energy is performed through direct burning. According to Cortez et al. [5], advantages of using this type of biomass include reduced pollution emissions. The sulfur and nitrogen contents present in the biomass are generally low, resulting in low pollutant gas emissions, such as SO₂, NO_x and N₂O during the combustion process. Although CO₂ is released by combusting biomass, the quantity does not exceed the amount produced during photosynthesis during plant growth. The continuing increase in the CO₂ content of the atmosphere due mainly to the combustion of fossil fuels is predicted to lead to global warming. For this reason, alternative sources of energy that will result in a decline in the release of CO₂ need to be identified. So-called CO₂-neutral energy sources are solar, wind and water power but also include the combustion of biomass.

Pyrolysis is another thermochemical technique to convert biomass and it has been considered highly promising due to the exceptional flexibility of the process, which is conducive to obtaining multiple products. The process causes the formation of a carbon-rich solid waste (coal) and a volatile fraction composed of condensable organic vapors (bio-oil) and non-condensable gases [6,7]. Bio-oil consists of two phases: an aqueous phase containing oxygenated organic compounds of lower molecular weight and a non-aqueous phase containing organic compounds (mainly aromatics). The organic compounds are a very interesting pyrolysis

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product because it can be used either directly as a fuel or as a source of chemicals. The possibility of producing chemical specialties and products of great added-value makes this process a very attractive option considering the current initiatives of seeking new renewable sources for clean energy production. The characteristics and properties of these products depend on the parameters that characterize the slow, fast or flash pyrolysis process; they also depend on the proportions of the components that constitute the biomass [8,9].

Dependent on the energy conversion process selected, particular material properties become important during subsequent processing. The most important chemical properties of biomass in dry conversion processes, which initially inform the possible fuel qualities are proximate analysis including moisture (M), ash, volatile matter (VM) and fixed carbon (FC) content, ultimate analysis (percentages of C, N, H, S and O), higher and lower heating value and lignocellulosic fractions. Thermal properties as temperature and degree of thermal degradation depend on the chemical properties.

Thermal conversion technologies can also use feedstocks with high moisture content but the overall energy balance for the conversion process is adversely impacted. The presence of water lowers the heating value of the fuel. It also increases the flue gas volume. This causes a decrease in the combustion efficiency. Furthermore the emissions of unburned fuel components (CO, carbohydrates, tars) rise as the water concentration increases, particularly when lumpy solid fuels are used, due to the decline in the combustion temperature caused by the cooling effect of the vapor. Moisture can vary between a low percentage, below 10%, for pre-dried biomass or as high as 50% in fresh crops [10].

The volatile matter and the fixed carbon contents provide a measure of the ease with which the biomass can be ignited and subsequently gasified, or oxidized, depending on the thermal conversion process. The volatile matter refers to the components released when fuel is heated at a high temperature, without counting moisture, being part combustible gases and part incombustible. Biomass generally has a high volatile matter. The more volatile a fuel the more reactive and the more easily it is ignited. The fixed carbon is the mass remaining after the release of volatile, excluding ash and moisture content. Volatile matter is from 65% to 85% for general biomass, and from 76% to 86% for woody biomass. Fixed carbon levels are generally expected from 7% to 20% [10].

Ash is the inorganic part of the fuel left after complete combustion. At high temperatures, during the combustion process, ash can be melted producing slag deposits in the furnace. The ash content affects both the handling and processing costs and biomass energy conversion cost. The yield and heating value decrease with the ash content. According García et al. [10], ash is expected to have values for commercial fuels from 0.6% to 9.8%, energy crops from 1% to 9.6%, cereals from 1.8% to 4.8% and industrial waste from 0.4% to 22.6%. General values may appear in a range from levels below 5–20%.

The heating value, also called calorific value or heat of combustion, defines the energy content of a biomass fuel and is one of the most important characteristic parameters for design calculations and numerical simulations of thermal systems in which biomass is used. Generally, the heating value of a fuel may be reported on two bases, the higher heating value or gross calorific value and the lower heating value or net calorific value. The higher heating value (HHV) refers to the heat released from the fuel combustion with the original and generated water in a condensed state, while the lower heating value (LHV) is based on gaseous water as the product. The heating value of a biomass fuel can be determined experimentally by employing an adiabatic bomb calorimeter, which measures the enthalpy change between reactants and products. Although different types of biomass are made up of similar

components (lignin, cellulose, hemicellulose) they do differ in their water and ash concentrations which explains the variations in their heating values [11,12]. Higher heating values for biomasses are expected to be between 15 and 19 MJ/kg for commercial fuels, such as chips, pellets and briquettes, energy crops, cereals, waste from the fruit processing industry, 19 and 22 MJ/kg for industrial wastes, 17 and 20 MJ/kg for tree leaves and 29 MJ/kg for vegetal coal [10].

Major elements contributing to the calorific value are carbon, hydrogen, nitrogen, oxygen and sulfur. Elemental analysis can be used to describe biomass fuels, determine their calorific values and their expected impact. The percentages of N, S and Cl provide an idea of the environmental impact of the use of a biomass fuel and corrosion process involved, while the concentrations of C, H and O allow the heating value and the theoretical ratio of combustion in thermoconversion systems to be determined. Traces of heavy metals are also usually present. Si, Al, Ti, Fe, Ca, Mg, Na, K, S and P are important in the characterization of the ash [10,13]. According García et al. [10] and Telmo et al. [12] for ultimate analysis of biomass, carbon is expected to have values between 45% and 54%, hydrogen from 5.6% to 7%, oxygen from 40% to 48%, nitrogen levels lower than 3%, and mostly under 1%, sulfur levels lower than 1%, and mostly under 0.4%.

Research in the bioenergy field has become increasingly relevant to Brazil because it is estimated that approximately 440 million tons of agro-industrial, agricultural and livestock waste and byproducts are produced annually. However, only a small fraction of this biomass, approximately 5–8%, is used in Brazil, whereas the use of such waste in other countries can reach up to 36% [14].

Little information is available in the literature regarding the use of wastes generated in banana culture as combustible biomass based on their thermochemical conversion through combustion and pyrolysis [15]. Some researchers have demonstrated the potential of generating energy from banana waste and these studies are based on the production of biogas through digestion process from banana peels, stalk, leaves and pseudostem [16,17], the production of briquettes from banana peels [18] and the generation of ethanol from banana peels and banana fruit [19,20].

In this study, banana culture wastes (leaves) were characterized through proximate and ultimate analyses, lignocellulosic fractions analysis, heating value analysis, thermogravimetric analysis (TG/DTG) and differential scanning calorimetry (DSC) to evaluate the use of the waste as a combustible biomass for generating energy and obtaining added-value products by combustion and pyrolysis processes.

2. Experimental study

The wet leaves samples were cut directly from the banana tree and the semi-dried samples were obtained from leaves that had fallen from the banana tree and were already undergoing a natural degradation process. The samples were grinded and sieved to produce particles less than 2.5 mm in size, according ASTM E828-81.

To correlate the respective composition with the thermal behavior of the biomass under characterization, chemical and physical analysis were performed. The heating value of biomass and the conditions for thermochemical conversion of biomass by pyrolysis and combustion are highly correlated with the content of ash, moisture, volatiles and lignocellulosic content including the elemental composition of carbon, hydrogen, sulfur and oxygen.

The proximate analysis was performed on the biomass samples for the determination of moisture, volatile matter, ash and fixed carbon contents following the ASTM standardized procedures. The moisture content was determined as the weight loss in a stove at 103 °C using the procedures given in ASTM E871-82. The volatile

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