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Recovery of fibers and biomethane from banana peduncles biomass through anaerobic digestion

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ABSTRACT

Banana crop produces large quantities of post-harvest biomass wastes. Some of them are a potential resource of raw materials such as natural fibers, which can be used as reinforcement for composite materials. The recovery of fibers, after bioconversion of the more digestible soft tissues to biogas was assessed for peduncles of three banana varieties (Grande Naine (GN), Pelipita (PPT) and CRBP969). Fibers were sieved out from the digestate. Biogas was monitored manometrically and with gas chromatography. PPT peduncle produced both the highest fibers recovery (0.2 g_DM_fiber/g_DM_initial_substrate) and methane production (260 ml_CH_4/g_COD_initial_substrate) after 74 days of anaerobic digestion. This variety was the most suitable candidate to combine both fiber recovery and biomethane production through anaerobic digestion. GN peduncle fibers degraded in less than 20 days. This variety was more convenient for biomethane production (around 210 ml_CH_4/g_COD$_{\text{initial_substrate}}$). The amount and the quality of recovered fibers strongly depended both on the duration of anaerobic digestion and the banana variety. This work showed that anaerobic digestion was an effective bioprocess alternative to mechanical decortication and biological retting processes for fiber extraction from banana peduncles biomass.

Introduction

Banana is now widely cultivated in Asia (continent of origin), Latin America, Caribbean countries, and Africa, where its fruits contribute to food security and socio-economical life. Edible varieties arose from hybridization of *Musa acuminata* (AA) and *Musa balbisiana* (BB) (Stover and Simmonds, 1987). With a world production of more than 138 million ton in 2010, bananas and plantains are the seventh most important food crop after maize, rice, wheat, potato, soybean and cassava (FAOSTAT, 2012). But, fruit represents only about one third of the total fresh banana plant weight (Kamdem et al. 2011). For the year 2012, production reached 1.4 million ton in Cameroon, the African leading producer of bananas and plantains, resulting in about 90,000 ton as dry matter of agro-industrial residues (FAOSTAT, 2012).

Banana intensive cropping produces large quantities of post-harvest organic residues such as pseudo-stems, peduncles, bulbs, leaf sheath and rachis, representing about 70% of the total fresh plant weight. These residues are very often gathered as big roadside piles within which non-controlled fermentation leads to emission of volatile organic compounds, greenhouse gases, and contributes to spread mosquitoes and pathogens, with the corresponding environmental and health burdens (Awedem et al., 2016). Some of these residues are mainly constituted of cellulose and lignin, which are difficult to degrade under normal windrow composting conditions (Chanakya and Sreesha, 2012; Tiappi et al., 2015). They are a potential resource of natural fibers, which can be used in papers and textile, and as reinforcement for composite materials for aeronautics and cars (Baiardo et al., 2002; Gañán et al., 2008; Saikia et al., 1997).

In spite of potential applications of this type of residues and even their environmental impact, very few works related to fiber extraction and isolation have been reported. Some results have been published on the fiber isolation from banana pseudo-stem, leaf sheath and rachis through mechanical decortication and biological retting processes.

Abbreviations: BMP, Biochemical methane potential; CARBAP, African Research Centre on Bananas and Plantains; CRBP, Previous name of CARBAP; COD, Chemical oxygen demand; DM, Dry matter; FM, Fresh matter; GC, Gas chromatography; GN, Grande Naine; PHP, Plantations Haut Penja; PPTA, Pelipita; VS, Volatile solids.

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Table 1
Botanical accession of the studied varieties.

Variety	Analysis code	Specie/genetic group	Subgroup	Origin	Fruit type
Grande Naine	GN	AAA	Cavendish	Asia (China/Vietnam)	Dessert
Pelipita	PPT	ABB	Pelipita	Philippines	Cooking banana
CRBP969	CRBP969	AAAB	(hybrid plantain)	CARBAP (Cameroon)	Plantain

Mechanical decortication leads to deformation or breakages of β-glucosidic linkages present in cellulose and hemicellulose, while biological retting process leads to chemical changes of non-cellulosic components of the cell wall, such as pectins (Chanakya and Sreesha, 2012; Gañán et al., 2008). The recalcitrant properties of this biomass limit the recovery of fibers by both extraction methods (Chanakya and Sreesha, 2012; Gañán et al., 2004, 2008; Saikia et al., 1997). Other results have been reported on the bioconversion of banana residues to biogas (Bardiya et al., 1996; Chanakya et al., 2009; Chananchida et al. 2014; Gunaseelan, 2004; Kalia et al. 2000; Kamdem et al. 2013; Awedem et al., 2016). However, the bioconversion yields for biogas production found in the literature are currently below 50% *w*/w (e.g. 48% *w*/w for banana stem (Kalia et al. 2000); 46, 42, 40 and 28% *w*/w for banana peduncles, bulbs, leaf sheaths and leaf blades, respectively (Kamdem et al. 2013)), showing that these substrates are not fully biodegraded, even after many days of degradation time and the use of physical, chemical and mechanical pretreatments.

Nowadays, chemical, physicochemical and mechanical methods of pretreatment are investigated to improve degradation of the less digestible fibers. However, the additional costs required for this stage (such as high temperature, pressure or enzymes) can make the process more expensive and lower its industrial attractiveness (Dionisi et al., 2015). In the opposite way, the present work investigates anaerobic digestion as a bioprocess for combining both fiber recovery and biogas production. To the best of our knowledge, there has been no study with such an approach with banana peduncles biomass. We compared the degradation of soft tissues from peduncles of three banana varieties with contrasted properties (Grande Naine (export dessert banana), Pelipita (locally used plantain), CRBP969 (phytopathogen resistant hybrid-plantain)), to release fibers. We assessed the recovery yield of both biogas and fibers. The influence of the duration of anaerobic digestion on fiber recovery as well as fibers stiffness during the bioprocess was also investigated.

Materials and methods

Sample preparation

Banana peduncles of the varieties Grande Naine (GN, dessert banana), CRBP969 (previous name of CARBAP, hybrid plantain), and Pelipita (PPT, cooking banana) were obtained from the *African Research Centre on Bananas and Plantains* (CARBAP) and *Plantations Haut Penja* (PHP, only for the variety Grande Naine), in Cameroon. The varieties selected for this study are described in Table 1 (Awedem et al., 2015; Tiappi et al., 2015; Awedem et al., 2016). After the mature fruits had been harvested, the peduncles were collected. The harvested peduncles were cut into pieces with size of approximately 80 cm and stored at −20 °C. The samples were thawed just before use and cut with a knife into sticks of 4.5 cm length and maximum 2.5 cm diameter.

Chemical analysis

The dry matter (DM) content of the samples was determined after drying at 105 °C for at least 24 h. The dry residue was subsequently burned in a furnace at 550 °C for 24 h. The mass loss was defined as the volatile solids (VS). The chemical oxygen demand (COD) and ash content were determined according to Standard Methods (Clesceri et al., 1999). Soluble COD (CODs) was measured with the COD Cell Test method (Spectroquant® kits 1.14541.0001 and 1.14555.0001, Spectroquant® ThermoReactor 620, Photometer SQ200, Merck Germany) according to the provider's instructions. Cellulose, hemicelluloses and lignin contents were analyzed following the Van Soest method as extensively described in another study (Escarnot et al., 2010). Their contents were measured gravimetrically as residues of sequential non-enzymatic extraction procedures leaving the neutral detergent fibers (NDF, includes hemicelluloses, cellulose and lignin), the acid detergent fibers (ADF, includes cellulose and lignin) and acid detergent lignin (ADL). Then, the neutral detergent fiber (NDF) method provided data on the cellulose and hemicelluloses content by difference.

Anaerobic digestion

The anaerobic digestion assay was performed according to the method described by Awedem et al. (2016). The inoculum was prepared by incubating for 10 days at 35 °C under anaerobic conditions, a methanogenic primary inoculum maintained in the laboratory, with freshly collected activated sludge, as a substrate in a ratio of 0.3 $g_{COD-activated\_sludge}/g_{COD-methanogenic\_primary\_inoculum}$. The activated sludge was collected at the Chastre municipal wastewater treatment plant (Mont-Saint-Guibert, Belgium). Upon arrival in the laboratory, the sludge was left to settle in the dark at 4 °C for 24 h. The clear

Fig. 1. Fiber recovery (left: digestate on a sieve; right: fibers cleaning into a beaker).