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Anaerobic retting of banana and arecanut wastes in a plug flow digester for recovery of fiber, biogas and compost

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ABSTRACT

Leaves and leaf sheath of banana and areca husk (*Areca catechu*) constitute an important component of urban solid waste (USW) in India which are difficult to degrade under normal windrow composting conditions. A successful method of anaerobic digestion built around the fermentation properties of these feedstock has been evolved which uses no moving parts, pretreatment or energy input while enabling recovery of four products: fiber, biogas, compost and pest repellent. An SRT of 27 d and 35 d was found to be optimum for fiber recovery for banana leaf and areca husk, respectively. Banana leaf showed a degradation pattern different from other leaves with slow pectin-1 degradation (80%) and 40% lignin removal in 27 d SRT. Areca husk however, showed a degradation pattern similar to other plant biomass. Mass recovery levels for banana leaf were fiber—20%, biogas—70% (400 ml/g TS) and compost—10%. For areca husk recovery was fiber—50%, biogas—45% (250 ml/g TS) and compost—5%.

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Introduction

Banana leaves (40 million tons, Mt/yr) rachis, pseudostems and areca husk are the major agricultural residues and a key component of urban solid wastes, USW, in India (Bhat et al., 2007; Ramachandra et al., 2008; Shah et al., 2005). Banana leaves are also used daily at homes, in temples, at community eateries (Choultries), restaurants, etc. as a traditionally used disposable plate and also to pack cooked food. India ranks first in area and production of arecanut (*Areca catechu* Linnaeus). During processing, ripe fruits are dehusked manually, nuts extracted and husks discarded in nearby fields and occasionally used as fuel (Tholath et al., 2005).

In banana leaf, fibers are lignocellulosic in nature with a diameter of 5.6–11 μm with an external wall thickness of 2.2 μm consisting of helically wound cellulose microfibrils in an amorphous matrix of lignin and hemicellulose. Therefore, a high retting exposure time is required for progressive separation of fiber bundles (Gañán et al., 2008; Mukhopadhyay et al., 2008). Banana leaf fibers consists of ß-(1-4)-D-glucose and the cellulose chains are arranged in crystalline microfibrils surrounded by non cellulosic matrix (Zuluaga et al., 2007). The non cellulosic matter consists of 25–30% protopectin, 1–2% insoluble pectin, 20–25% hemicellulose and 10–12% lignin, the rest being cellulose (Shah et al., 2005).

Areca husk fiber has an average filament length of 40 mm and composed of cellulose with varying proportions of hemicellulose (35–64.8%), lignin (13.0–26.0%), pectin and proto-pectin. The husk constitutes 60–80% of the total weight of fresh fruits and has of two types of filaments, inner hard fibers and outer soft fibers (Tholath et al., 2005).

Mechanical, chemical and biological retting processes have been developed for extraction of fiber from these two residues. Mechanical decortication of fiber bundles leads to breakages while chemical retting allows delignification and removal of hemicellulose that are ester linked in banana leaf and affect fiber strength (Gañán et al., 2008). Aerobic dew retting leads to low quality coarse fibers with partial breakdown of cellulose. Pectinolytic activity during water retting (anaerobic) sets the fiber free and is suitable for small-scale fiber production (Skomra, 2006).

These agro-residues require a long degradation time when composted or left in open dumps or landfills and leads to methane generation (Banik et al., 1993; Mashandete et al., 2008). These feedstocks can be anaerobically degraded to four products i) fiber (cloth/paper), ii) compost, iii) biogas (fuel) and iv) digester liquid (for recycling or use as pest repellent; (Chanakya et al., 2009)). Natural fibers such as these have attractive technical, economical and environmental advantages (Gañán et al., 2008). Biogas plants producing multiple products from such feedstocks will open new avenues for use of agro-residues and USW with a low environmental footprint and higher sustainability. The process flow diagram for extracting such value added products from Banana leaf and Areca husk is shown in Fig. 1.

Materials and methods

The fermentation properties of banana leaf (50 g fresh) and areca husk (250 g) were studied by fermenting them in nylon mesh bags

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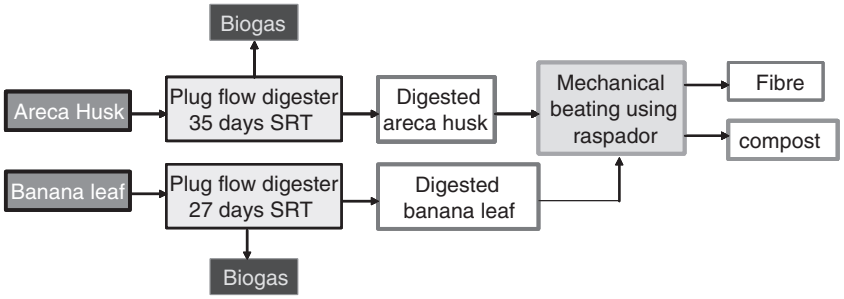


Fig. 1. Fiber recovery process by anaerobic retting in a plug flow digester.

(6 mm pore size) placed in plug flow digester [Fig. 2, (Chanakya et al., 2004)] developed by Center for Sustainable technologies (CST, Indian Institute of Science, IISc Bangalore). Samples in nylon mesh bags were kept submerged in the outlet chamber of the biogas plant. This was to avoid disturbances and possible contamination from daily operation. These were digested for 30 d (days, banana leaf) or 50 d (areca husk). Digested samples were removed on pre determined fermentation periods (3, 6, 10, 14, 17, 20, 24, 27, 30, 33, 36, 40, 46 and 50 days, 4 replicates) and were checked for wet and dry weight changes. Two replicates were used for fiber extraction and other two were dried in oven at 90 °C (24 h) to analyze residual constituents.

To separate the fiber from the non-fibrous fraction and to estimate the extractable fiber weight, fermented material was blended for 2 min in a laboratory blender along with 100 ml of water. The slurry after blending (compost residue) as well as the fiber mass was dried at 90 °C for further analysis.

Physico-chemical analyses

The constituents of feedstocks (soluble pectin, insoluble pectin, hemicellulose, cellulose and lignin) were determined by sequential solubilization [(Chesson, 1978), 2 replicates, 1 g each]. One gram oven-dried samples were extracted sequentially in hot water, 0.5 M ammonium oxalate, 0.5 M H_2SO_4, 72% ice cold H_2SO_4 (twice). The residue left behind after each extraction step was oven dried at 90 °C and weight loss was determined. In this leaf biomass feedstock the weight lost after each extraction represented hot water soluble pectin-1, oxalate soluble pectin-2, hemicellulose, cellulose and lignin (residue). The extent and pattern of decomposition of banana leaf were also monitored by light microscopy. Banana leaf samples of different stages were fixed in methanol: acetic acid (3:1) for 48 h and subsequently dyed with lactophenol blue (aniline) for 8 h. The gas production potential was determined by biological methane potential assay (BMP) (Chanakya et al., 2009) carried out in 135 mL serum vials with 1.0% of dried and powdered (laboratory blender) feedstock to which 50 mL of inoculum was added. The headspace was first purged rapidly with biogas and then the septum was sealed onto the vial. Within an hour, these vials were purged with oxygen-free nitrogen to remove all traces of methane and oxygen if present (Chanakya et al., 2009). These vials in duplicates were incubated at room temperature (28 °C) and the volume of gas produced was measured in a burette by downward displacement. Gas composition was determined in a gas chromatograph (GC) using a Porapak-Q column at 40 °C and thermal conductivity detector (Mayura Analytical, Bangalore).

Results and discussions

Efficiency of the process

Banana leaves were retted for a period of 30 d solid retention time (SRT, chosen based on a pilot study, Fig. 3a). The distribution of feedstock and products after digestion, namely fiber, total dry matter, residue after fiber extraction and digesters liquid is presented. The decomposition rate and pattern of banana leaves exhibited three clear stages. A 3 d period was required for initiation of retting, which was characterized by low weight loss and fiber recovery. Next, from days 6–17 there was an increasing trend of fiber recovery. During this period fiber fraction was high (15–18%) but the quality, separability and recovery by blending were poor. In the third stage, from 20 d, the rate of decomposition slowed down (Fig. 3a), while the quality and extractable fiber yield improved. For a good retting process there is a need to maximize two parameters — ease of fiber extraction and quantity of fiber extracted per unit mass. The highest level of fiber recovery and best quality occurred on day 27. The compost obtained on 27 d of fermentation accounted for 5% of the original TS added, suggesting that economics of compost recovery would be poor when the process is optimized for fiber recovery. However, considering the price of fiber would always be higher than compost it would be economically more sustainable. In this study, the level of moisture held in the feedstock that is later converted to digester liquid (pest repellent) could not be quantified. The excess digester liquid is expected to have both plant nutrients and pest repellent properties (Rodriguez-Delgado et al., 2011). Its recovery and reuse would improve the economics and sustainability.

Arecanut husks required a long SRT for good fiber separation compared to banana leaves and hence were retted for 50 days (Fig. 3b). There was no initial start up period for retting as in case of banana

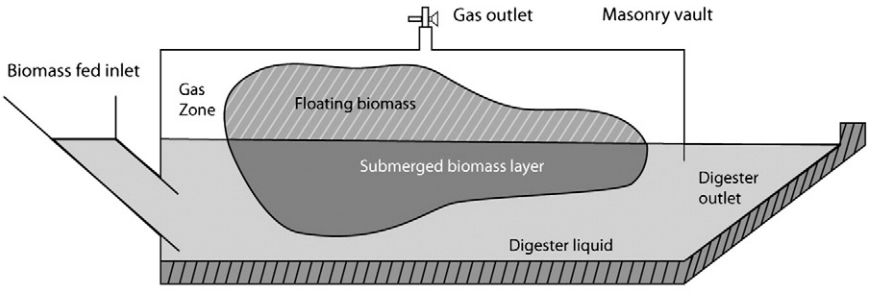


Fig. 2. Plug flow digester.

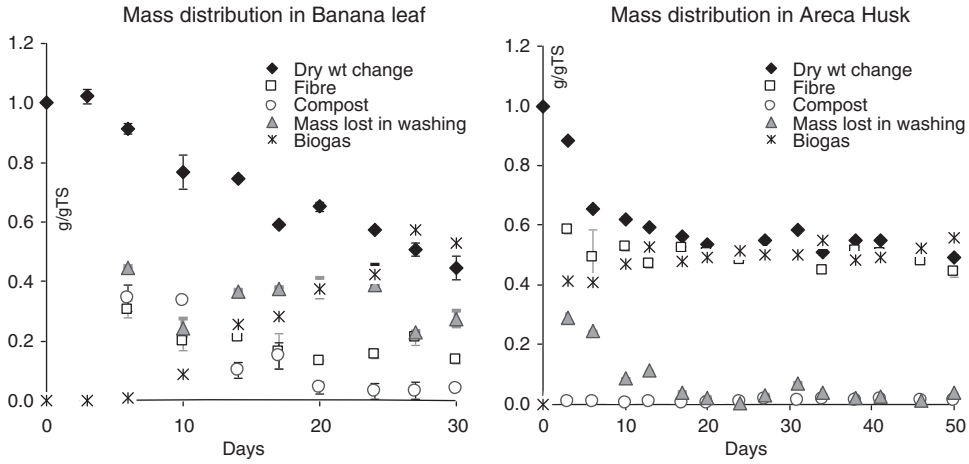


Fig. 3. a: Mass distribution in banana leaf and b: Mass distribution in areca husk.

leaf and fiber extraction was possible from day 3. Fiber fraction recovered on day 3 was high (58%) but fiber quality was poor. Fiber recovery remained at 50% of TS fed between 24 and 50 d (the best quality was at 35 d). At this stage of decomposition the compost recovered was low (2%). While a 50% TS loss required 30 d in banana leaf achieving a similar degradation required 50 d for areca husk.

Fiber recovery

The fiber fraction recovered at various stages is shown in Fig. 3. The maximum fiber recovery for banana leaf was found on 27 d and 35 d for areca husk (Fig. 5). Fiber recovery for banana leaf was 20% of original TS and 40% of the retted TS on 27 d. In case of areca husk the fiber recovery was 49% of the original TS added and 98% of the residual TS. Banana fibers extracted on 27 d were found to be long, between 20 and 30 cm, fine and very flexible (Fig. 5c). Other yarn properties need to be determined. Areca fibers were short and 5–7 cm long (Fig. 5d). Areca husk fibers recovered by this process were of 2 types, coarse and fine. Both the types of fibers were of the same length but differed significantly in their diameter and stiffness. Their suitability for various other applications and other textile and rope making properties need to be determined. From this we conclude that under the current conditions of fermentation namely (a) completely submerged in digester liquid (b) undisturbed by daily operation and (c) ambient temperature regime of 18–24 °C, the optimum solid retention time for highest fiber recovery is 27 d for banana leaf and 35 d for areca husk.

Decomposition pattern

The decomposition patterns of banana leaf and areca husk are shown in Figs. 3a and b, respectively.

In banana leaf, degradation of hot water soluble substances (pectin-1) was slow (80% loss in 27 d, Fig. 4a). Such a slow pectin-1 degradation was different from most other plant species studied (Chanakya et al., 1997; Chanakya et al., 2009). Oxalate soluble pectin degraded rapidly, as in other plant species, losing 90% of this fraction in 3 d (Chanakya et al., 1997; Chanakya et al., 2009). Degradation of hemicellulose was slow up to a period of 17 d (<20%) and reached 50% in 30 d (Fig. 4a). Cellulose degradation was slow reaching 33% in 30 d. Lignin removal reached 40% in 30 d and was gradual. Lignin is considered to be recalcitrant under anaerobic conditions. This pattern of 40% lignin loss found among many trials is different from other feedstocks studied before.

A microscopic section of undigested and partially digested banana leaves is shown in Fig. 5a. In banana leaves the vascular bundles are arranged parallel to each other with equal spacing between each vascular bundle. The space between the vascular bundles is characterized by cementing, equally spaced, ladder-like bridges connecting vascular bundles. At this stage of research the composition of these bridges is not clear. No breakage of bridges connecting vascular bundles was visible till day 14, while on day 17 over 50% were broken. On day 30, >90% of the connecting channels were lost (presumed decomposed, Fig. 5b). These observations suggested that in 30 d no damage was caused to the vascular bundles and 20% of the fed TS could be

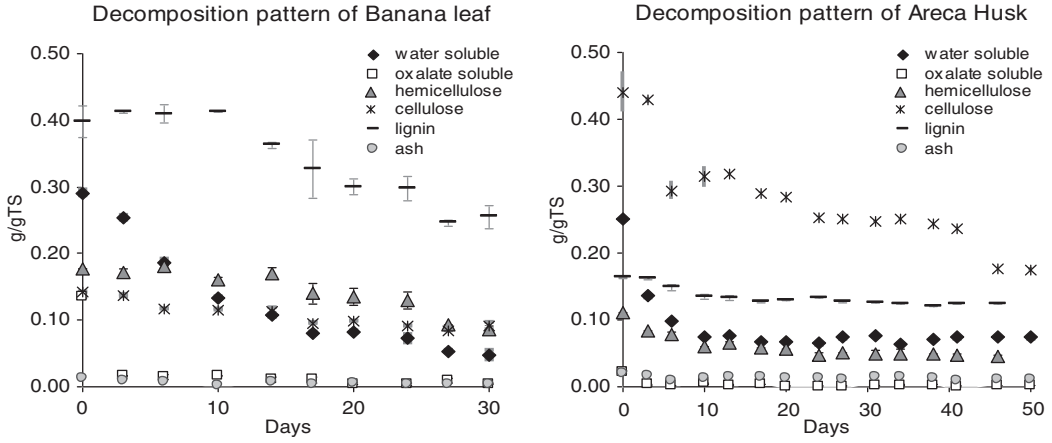


Fig. 4. a: Decomposition pattern of banana leaf, b: Areca husk.

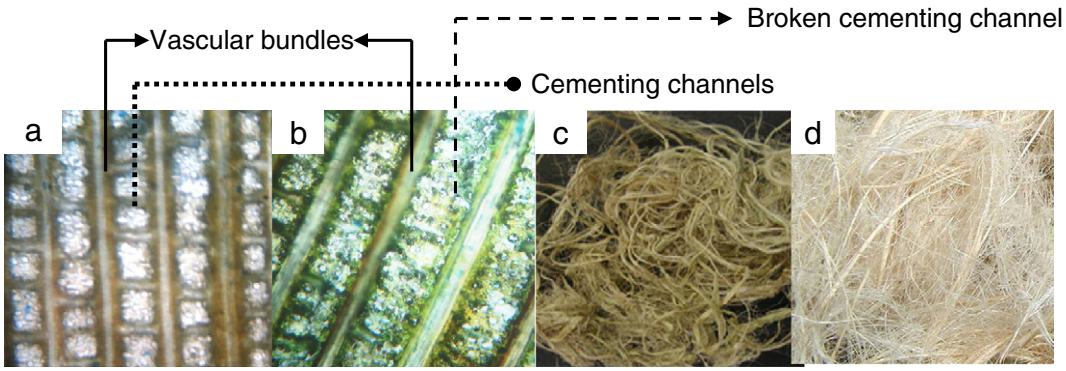


Fig. 5. a: Cross section of undigested banana leaf, b: Cross section of digested banana leaf, c: Banana leaf fiber, d: Areca husk fiber.

extracted as fiber. This also suggested a pattern of degradation in which the microbes attacked the outer cementing material between two vascular bundles first and setting the vascular bundles free and such a pattern has not been reported earlier.

In case of Areca husk, pectin-1 degraded rapidly achieving a 72% loss in 10 d and remained at this level (similar to other leaf biomass, Fig. 3b) (Chanakya et al., 1997). Oxalate pectin content was low and was lost rapidly. Hemicellulose removal could be detected in the digested areca husk samples till 15 d. Cellulose loss was rapid initially and slowed down after 5 d, 60% of cellulose was lost in 50 d. Lignin remained recalcitrant and in 30 d with <25% of degradation. After 35 d of anaerobic degradation of areca husk (of the original fraction), 25% pectin-1, 13% pectin-2, 38% hemicellulose, 57% cellulose and 73% lignin remained undigested.

Biogas production

Banana leaf and Areca husk were fermented at 1% TS in a BMP assay that showed good biogas production without VFA accumulation. Biogas production reached levels above 400 ml/g TS wherein banana leaves decomposed rapidly while areca husk achieved this slowly (Table 1). At a 30 d SRT banana leaf and areca husk produced 350 and 200 ml of biogas/g TS, respectively. Such gas production potential has been reported for many feedstocks, such as lawn grass, *Artocarpus*, rice straw, sugarcane trash, *Parthenium*, bagasse etc.(Chanakya et al., 1999, 2009; Chanakya and Moletta 2005). The biogas composition from banana leaf (27 d) and areca husk (35 d) was 60% methane and 40% carbon dioxide around day 15, resembling a typical biomass feedstock and not subject to any methanogenic inhibition. The efficiency of the process to recover biogas as well as the fraction recoverable as fiber and compost was monitored by measuring the TS and VS lost during fermentation process (Table 1).

Table 1
TS loss and biogas yield of banana leaf and areca husk.

Days	Areca husk			Banana leaf		
	Fresh wt after digestion	Dry wt	BMP 1% TS	Fresh wt after digestion	Dry wt	BMP 1% TS
	g/gTS	g/gTS	Biogas ml/gTS	g/gTS	g/gTS	Biogas ml/gTS
0	3.571	1.000	0	6.199	1.000	0
3	3.683	0.814	0	7.950	1.012	42.8
6	3.343	0.657	0	7.902	0.925	82.4
10	3.221	0.636	24	8.561	0.766	146.0
13	2.907	0.593	47.2	7.746	0.733	213.2
17	2.921	0.564	50.1	7.254	0.591	262.0
20	2.879	0.536	72.6	6.079	0.627	300.0
24	2.854	0.500	86	5.264	0.519	328.4
27	3.247	0.550	128.4	6.331	0.495	350.2
31	2.847	0.586	164.8	4.293	0.441	400.1
34	2.669	0.486	192.8	–	–	–
38	2.861	0.550	212.8	–	–	–
41	2.821	0.593	225.5	–	–	–
46	2.736	0.507	231.7	–	–	–
50	2.797	0.529	252.6	–	–	–

Conclusion

Banana leaf and areca husk components of USW and rural residues may be anaerobically fermented to provide multiple product fiber (20 and 50% of added weight from banana and areca, respectively), biogas (400 ml/g total solids), compost and digester liquid (pest repellent) increasing the value of products and thereby economic sustainability of the waste disposal system. In India, even if only half of the banana leaves are collected and fermented to biogas and fiber, this will yield 1.6 Bn m^3 biogas and 0.8 million tons of fiber. The pseudostem, about three times the weight of leaves, can be used to triple the gas and fiber yield estimated above and is therefore an attractive bioenergy option to pursue.

Acknowledgments

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References

Banik A, Sen M, Sen SP. Methane emission from jute-retting tanks. Ecol Eng 1993;2:73–9.
Bhat R, Sujatha S, Balasinha D. Impact of drip fertigation on productivity of arecanut (*Areca catechu* L). Agric Waste Manage 2007;90:101–11.
Chanakya HN, Moletta R. Performance and functioning of USW plug-flow reactors in a 3-zone fermentation model. Proc Fourth Int Symp Anaerobic Digestion Solid Wastes, Copenhagen 2005;1:277–84.
Chanakya HN, Venkatsubramaniyam R, Modak J. Fermentation and methanogenic characteristics of leafy biomass feedstocks in a solid phase biogas fermentor. Bioresour Technol 1997;62:71–8.
Chanakya HN, Srikumar KG, Anand V, Modak J, Jagadish KS. Fermentation properties of agro-residues, leaf biomass and urban market garbage in a solid phase biogas fermenter. Biomass Bioenergy 1999;16:417–29.
Chanakya HN, Rajabapaiah P, Modak JM. Evolving biomass-based biogas plants: The ASTRA experience current science 87, no. 7; 2004.
Chanakya HN, Sharma I, Ramachandra TV. Micro-scale anaerobic digestion of point source components of organic fraction of municipal solid waste. Waste Manag 2009;29:1306–12.
Chesson A. Maceration of linen flax under anaerobic conditions. J Appl Bacteriol 1978;45:219–30.
Gañán P, Zuluaga R, Restrepo A, Labidi J, Mondragon I. Plantain fibre bundles isolated from Colombian agro-industrial residues. Bioresour Technol 2008;99:486–91.
Mashandete MA, Björnsson L, Kajumulo KA, Steven TR, Bo Mattiasson. Two-stage anaerobic digestion of aerobic pre-treated sisal leaf decortications residues: hydrolases activities and biogas production profile. Afr J Biochem Res 2008;2:211–8.
Mukhopadhyay S, Fangueiro R, Arpaç Y, Şentürk Ü. Banana fibres — variability and fracture behaviour. J Eng Fibres Fabr 2008;3(2).
Ramachandra YL, Narayanamurthy G, Rai Padmalatha S, Manohara TN, Kavitha BT. Areca Husk: an inexpensive substrate for citric acid production by *Aspergillus niger* under solid state fermentation. Indian J Biotechnol 2008;7:99-102.

Rodriguez-Delgado MA, Gonzalez-Curbelo MA, Hernandez-Borges J, Ravelo-Perez ML. Insectisides extraction from banana leaves using modified QuEChERS method. Food Chem 2011;125:1083–90.

Shah MP, Reddy GV, Banerjee R, Ravindra Babu P, Kothari IL. Microbial degradation of banana waste under solid state bioprocessing using two lignocellulolytic fungi (Phylosticta spp. MPS-001 and Aspergillus spp. MPS-002). Process Biochem 2005;40:445–51.

Skomra, E., 2006.A comparative study of athletic apparel made from cotton/flax, cotton/polyester and polyester/flax blends. Thesis Submitted to the Department of School of Technology Studies, Eastern Michigan University.

Tholath AE, Akhila R, Gopinadha Kurup. Biosoftening of arecanut fibre for value added products. Biochem Eng J 2005;25:237–42.

Zuluaga R, Putaux Jean-Luc, Restrepo A, Mondragon I, Gan˜ a´n P. Cellulose microfibrils from banana farming residues: isolation and characterization. Cellulose 2007;14:585–92.