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AUDITING AND CHARACTERISATION OF SISAL PROCESSING WASTE: A BIORESOURCE FOR VALUE ADDITION

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ABSTRACT

The sisal industry in Kenya has been among the world leading producer of sisal. During sisal leaf decortications, only 2.7-7.3% of the leaf produces the fiber. Through auditing, in the year 2010, Kenya generated 611, 875 tonnes and 3, 511, 900 m^3 of sisal solid waste and wastewater, respectively. Total and volatile solids, cellulose and hemicelluloses contents in the wastes were in the ranges of 12-84%, 67-83%, 55.7-76.7% and 3.7-21.6% on dry weight basis, respectively. This study has shown anaerobic co-digestion of solid sisal waste with cow manure is a feasible process with normalised methane yields of 0.301 and m^3/KgVS.

Keywords: sisal, fiber, decortications, auditing, biogas.

INTRODUCTION

Agave sisalana Perrine, popularly known as sisal, belongs to the genus Agave of the order *Asparagales* and to the *Agavaceae* family, and more than 200 species plus 47 intraspecific categories have been identified [1]. The Agaves are indigenous to tropical and sub-tropical regions of Southern America, Mexico, Southern Coast of United States of America and the Caribbean Island [2]. It was introduced to Tanzania by a German agronomist in 1893 who imported bulbils from Florida, USA. From there, sisal spread to Kenya and other parts of East, Central and Southern Africa [3]. Sisal is mainly grown for its fibre, the most common use of which is making twines, ropes and other forms of cordage. The plant reproduces itself vegetatively as suckers and bulbils.

The need for value addition of agro-industrial waste products, which may become useful to society, has grown in recent years. Sisal leaf decortications residue is one of the most abundant agro-industrial residues in East African. Only 2.7-7.3% of the decortications of the sisal leaves produce the hard fiber that is used for various purposes depending on the age of the plant s well as the efficiency of the decortications process; the remaining 97.3-92.7% [4] consists of solid waste (mucilage) and waste liquid (juice of the sisal) that are normally discarded by sisal farms [5].These wastes are untreated, disposed of and in most cases burnt, dumped in water bodies and/or land filled; such practices are not sustainable and contribute to environmental pollution [6]. Traditional sisal leaf wet decortications technology generates 100 $m^3$and 25 tonnes of wastewater and solid residues, respectively per tonne of sisal fibre produced [7]. With projected 45,000 tonnes production of sisal fibres for the year 2007 in Tanzania an equivalent of 4.5 million m^3 of sisal decortications wastewater and 1, 125, 000 tonnes of solid sisal decortications residues were generated. So far there is no documented record of the sisal waste generated by the Kenyan sisal industries.

Sisal waste principally contains plant tissues (lignocellulosic biomass), primary and secondary metabolites, and water. Previously, attempts have been made to utilize sisal waste as pesticides [8], fertilizer [9], lactic acid production [10], animal feed [11] and Inulin for bioethanol production [12]. Laboratory scale research has been carried out on utilization of the waste for biogas production [5], [13]. The first large scale (1,700m^3) sisal waste fed biogas plant in the world located at the Katani Ltd's estate at Hale, Tanga, with a capacity to produce 300 kilowatts of electricity and bio-fertilizer commissioned in the year 2007 in Tanzania [14]. Sisal waste has been reported [15] to have insecticidal properties particularly against larvae of mosquitoes, which transmit tropical diseases. The current waste management practices at Kilifi Plantations Ltd are summarized in (Figure-1) below.

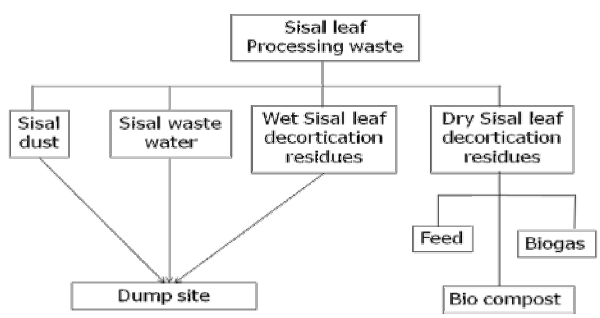

Figure-1. Sisal waste utilization scheme.

Applied research on sisal waste during the past decades has been largely basic emphasis, while recently, there has been a shift to development of new and promissory technologies to utilise sisal waste. Considerable development opportunities still exist and provide a future position of economic importance for *Agave* plants. The first stage in optimisation of waste reduction is to quantify and characterise the waste (solid and liquid) produced. Therefore this paper presents for the first time the results on the quantities and characteristics of the sisal waste at a sisal plantation located at Kilifi County in Kenya. Baseline biogas production data from sisal leaf decortications residues (SLDR-the leave green matter) and sisal leaf decortications waste (SLDW includes the short waste fiber) from the Kilifi sisal plantation are also reported for the first time.

MATERIALS AND METHODS

Materials for this study were obtained from Kilifi Plantation Limited, a sisal-processing factory at Kilifi County in Kenya. The plantation stretches from the beach-front to the mainland covering about 3, 000 acres of land. The waste included sisal leaf decortications waste (SLDW) and sisal leaf decortications residues (SLDR) while the liquid waste was the sisal leaf decortications wastewater, (SLDWW). The SLDW was sun-dried in a fully sunny day for 5 days and chopped to a size of 2-cm using a grass cutter, according to [13]. The SLDW was obtained from the drainage stream reagent bottles with airtight lids and carried to the laboratory for analysis. The active anaerobic inoculum to be used in AD experiments was obtained from 720 m^3 size inter stirred tank bioreactor digesting SLDR and cow dung manure.

Analytical methods, solid and liquid waste characterization

The Ash content, Moisture content, Crude Protein and Crude Fibre were analyzed in both the liquid and solid sisal fractions according to [16] and the respective values expressed in percentages of the respective weights (% by wt.). The lignin, hemicellulose, and cellulose were analyzed according to the method of [17]. The Total Solids (TS), Volatile Solids (VS), Total Nitrogen (TN), as well as the cations and anions which include Calcium, Magnesium, Manganese, Zinc, Copper, Cadmium, Sodium, Potassium, Sulphates, Phosphorous, Chlorides and Nitrates were analysed according to Standard methods for analysis of water and wastewater [18].

Baseline biogas determination

The SLDR and SLDW were evaluated for biogas production potential in 500 ml conical flasks with a working volume of 350 ml laboratory anaerobic batch bioreactors. The experimental set-up of the batch anaerobic bioreactors was done as previously described by [19]. Loading of SLDR and SLDW was done at varying sisal substrate and cow manure ratio in a fixed inoculum volume of 300 ml and varying dilutions with water. The biogas volume and composition was measured and analyzed after every 72 hours for 63 days in triplicates and a control consisting of the inoculum was included. Measurement of biogas volume was performed using 100 ml gas-tight glass syringe with a gas and the gas composition estimated by KOH concentrated absorption method according to [19]. Methane yields was calculated by taking the average difference of the methane produced by the control from the average methane produced by each set reactor and expressed in weight of volatile solids (gVS) in the substrate fed to the digester.

RESULTS AND DISCUSSIONS

Auditing of sisal processing waste

The processing of sisal leaves into clean fiber (decortications) in Kilifi Sisal Plantation Ltd has traditionally been done by the wet processing method utilizing large quantity of water estimated at 12m^3 per day (8 hours shift) resulting in production of large quantities of waste water. The estimated annual production of clean fibre is 480 tonnes resulting in generation of 8, 363 tones sisal solid sisal waste and 48, 000 m^3 of SLDWW. The production of 35,119 tonnes of clean fiber in Kenya in the year 2010 [21] resulted in generation of 611, 875 tones sisal solid sisal waste and 3, 511, 900m^3 of SLDWW.

The chemical composition of sisal liquid and solid wastes

The chemical composition of sisal liquid and solid wastes is tabulated (Table-1). Analysis of the various cations and anions indicate considerable high quantities in the wastewater with the major cation being Mn^{+2} whose content is 1071.36 mg/l, while the major anion being Cl^{-1} whose content is 1504.89 mg/l. The high salt content in solid sisal waste could possibly be due to the location of estate where sisal is grown at Kilifi along Indian Ocean coast line on which the sisal plant is grown as well as the water that is used in the wet decortications process of the sisal leaves. The water is obtained from a borehole, which is rich in chlorides and other mineral constituents, which explains the relatively high salt content of the waste water. The wastewater contained 1% w/w of protein and 8.83 mg/ml of total nitrogen. The wastewater has an acidic pH of 5.57 and this might be attributed to the relatively high content of sulphates (4571.52 mg/l) and chloride (1504.89 mg/l).

The moisture content of the fresh SLDW (76.78%) was similar to that of fresh SLDR (69.29%) while dried SLDW has lower moisture content (26.11%) due to the drying process. All the three wastes contains very little total nitrogen and crude protein content as compared to crude fibre content, where dried SLDW contained higher crude fibre (29.9%) than fresh SLDR (13.07%). This is probably due to the fibrous nature of the waste.

Table-1. The chemical composition of sisal liquid and solid wastes.

Parameters	**SLDWW**	**SLDR** (Fresh)	**SLDW** (Fresh)	**SLDW** (Dried)
Soluble proteins (mg/l)	1.0	-	-	-
Crude proteins (% by wt.)	-	1.0	1.0	<0.01
Total nitrogen (mg/l)	8.83	3.58	0.78	0.48
Moisture content (% by wt.)	-	60.29	76.78	26.11
Ash content (% by wt.)	-	3.37	97.41	82.44
Crude fibre (% by wt.)	-	13.07	-	29.9
Cations (mg/l)				
Calcium	816	10640	99.2	155.6
Magnesium	25.26	981.55	44.85	144.03
Manganese	1071.36	0.82	0.56	0.32
Zinc	83.64	0.03	0.001	0.01
Copper	1.01	0.04	12.77	11.41
Cadmium	0.01	0.07	<0.01	0.01
Sodium	371.32	26.62	24.81	58.31
Potassium	18	5.56	4.28	9.96
Iron	243.39	-	-	-
Anions (mg/l)				
Sulphates	4571.52	19633.92	266.2	682.62
Phosphorous	36.83	54.16	0.12	0.04
Chlorides	1504.89	6139.37	55.52	687.17
Nitrates	0.79	0.72	0.28	0.64
pH	5.6	8.1	8.3	8.2

Analysis of the cations and anions indicated relatively high quantities in the fresh SLDR with the major cations being Ca^{+2} ions whose content is 10, 640 mg/l, while the major anion being SO_4^{-2} whose content was 19, 633.92 mg/l. The fresh SLDW and dried SLDW had relatively lower values of the cations and anions where the dominant cation was Ca^{2+} (99.2 mg/l and 155.6 mg/l, respectively) while the dominant anion is SO_4^{-2} in fresh SLDW (266.2 mg/l) and Cl^- in dried SLDW (687.17 mg/l). The values are high possibly due to the unique salty soil on which the sisal plant is grown and the wet processing using borehole water, which is salty. The wastes contained very little Mn^{+2}, Zn^{+2}, Cd^{+2}, phosphorous and nitrates.

The composition of solid sisal decortications waste

The high organic carbon material content (fraction) measured as VS, organic carbon and total organic matter is an indication that these bioresources could serve as a possible alternative substrate for microbial growth. The composition of solid SLDR and SLDW are tabulated in (Table-2). The total solids and volatile solids in the SLDR were 12.7% and 67.7 %, respectively, which was lower than that reported previously (14.1% and 85.5%, respectively) [5]. The content of total solids and volatile solids in the SLDW is 84.09% and 83.25%, respectively, which is higher than in SLDR. This makes both SLDR as well as SLDW potential substrates for biogas production because according to [22], the high the VS content the more biogas generated from the substrate.

Analysis of the polysaccharides indicated that SLDR contained lignin (6.6%), cellulose (55.7%) and hemicellulose (3.7%), cellulose being the most dominant polysaccharide. These values were lower than those obtained by [5]. Content of the polysaccharides in SLDW was higher than in the SLDR. This is probably because of the fact that SLDW is fibrous in nature as it has higher values of NDF and ADF than SLDR. The difference in the various constituents may be possibly due to the area in which the plant is grown as well as the process of obtaining the waste during the decortications process.

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Table-2. Composition of sisal residues (means ± SD[b]).

Determination	SLDR	SLDW
Total solids , (TS) %	12.7±0.3	16.1±1.5
Volatile solids, VS (% of TS)	67.7±8	83.3±1
Total organic carbon[a]	44.1±0.8	49.4±0.4
Total organic matter	93.4±1.7	97.2±4.3
Neutral detergent fibres (NDF) [a]	39.5±2	69.0±8
Acid detergent fibres (ADF) [a]	35.8±0.9	47.4±8.3
Lignin [a]	6.6±2.4	4.5±2.7
Cellulose[a]	55.7±7.4	76.7±5.6
Hemicellulose[a]	3.7±2.6	21.6±7.2

[a] % of dry weight
[b]n=3

The presence of lignocellulosic biomass makes the substrate potentially suitable for use in the production of mushrooms as they are utilized by the mushroom mycelium as a source of nutrition [23]. In biogas production, the presence of lignocellulosic biomass has been regarded as the rate-limiting step [24]. This is due to the fact that the presence of the biomass in the substrate tends to float on the fluid surface in the digester during biogas production, leading to increased stirring expenses [25]. Thus the spent mushroom substrate is potentially suitable for use in the production of biogas. This is made possible by the ability of mushrooms to secrete a wide range of hydrolysing and oxidizing enzymes, which breaks down natural lignocellulosic biomass into simple compounds [26]. It has been [27] reported that, changes that take place in the residues during bioconversion of agro-substrates during mushroom cultivation formed "mycoprotein" which, resulted in increased nitrogen content that subsequently increased biogas production in the spent mushroom substrate over those that had not been bio converted.

Baseline biogas production from SLDW, SLDR and cow dung

Baseline biogas studies on SLDR and SLDW revealed that the waste is a potential feedstock for anaerobic digestion in the production of biogas. This is attributed to the abundance and richness in easily biodegradable substrates such as carbohydrates, which is the main source of VS. The waste was co-digested with cow manure to improve on methane yield. Co-digestion of different kinds of waste normally leads to either synergism or antagonism in anaerobic digestion for methane production. Synergism occurs when an additional substrate contributes essential nutrients needed for bacterial growth or dilutes the toxic effect of already present compounds according to [28]. Co-digestion of SLDR with cow manure produced methane yields in the range of 0.075 to 0.329 m^3/kg VS $_{(added)}$ with dilution factors ranging from 0.03-0.29 (Figure-2)

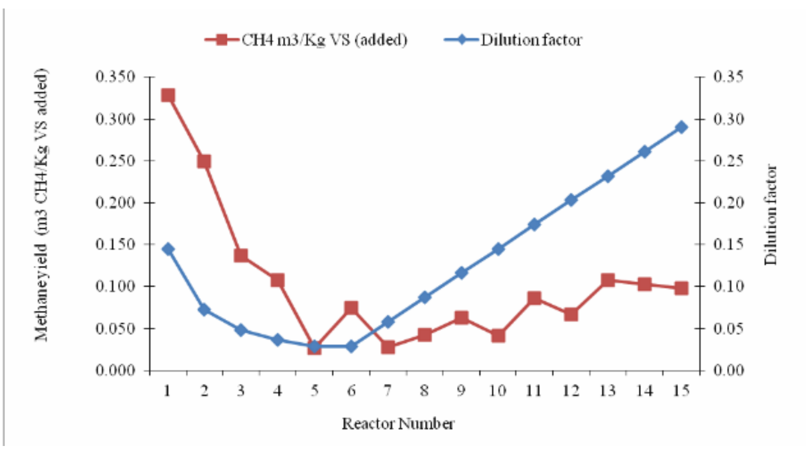

Figure-2. Methane production from SLDR and Cow dung with different dilutions.

while co-digestion of SLDW with cow manure produced methane yields in the range of 0.112 to 0.282 m^3/kg VS $_{(added)}$ with dilution factors ranging from 0.12-1.58 (Figure-3). From the results, the reactor with the lowest feed concentration gave higher methane yield as compared to those with high feed concentration.

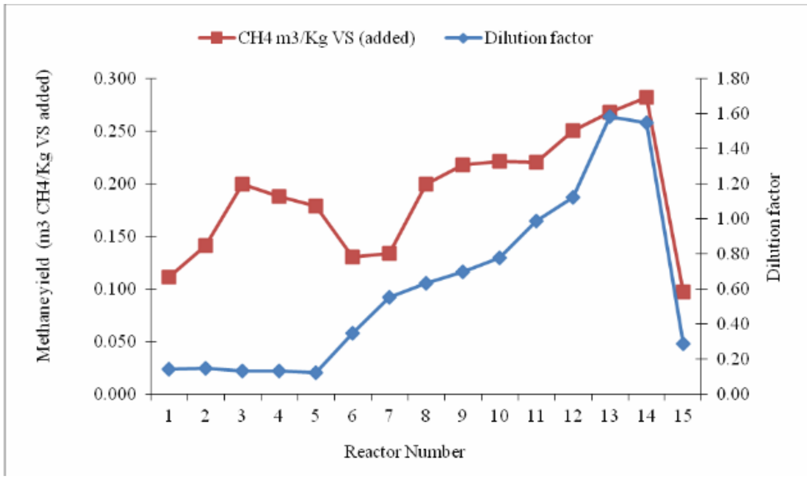

Figure-3. Methane production from SLDW and Cow dung with different dilutions.

Normalised methane yield of 0.329 m^3/kg VS $_{(added)}$ from the highest yielding reactor results in production of 0.301 m^3/kg VS $_{(added)}$. These results revealed that the 8, 363 tonnes of solid sisal waste generated annually at Kilifi Plantation limited has a potential of producing 2, 520, 602 m^3 of methane (biogas), with Kenya having an annual generation potential of 184, 174, 375 $m^3$of methane (biogas) from the 611, 875 tonnes sisal solid waste generated in 2010. This is equivalent to 155, 074, 824 litres of petroleum oil and 1, 834, 376, 775 kWh/$m^3$and 239, 426, 688 Kgs of firewood equivalent as tabulated in 3. This estimation was based on the fact that one cubic metre of methane is equivalent to 0.842 Kg of diesel oil and has a calorific value of9.96 kWh/m^3 [29].

Table-3. Determination of biogas production potential from solid sisal waste in Kenya.

Parameter	Annual quantity	Units/year
Total sisal solid waste generated in 2010	611, 875, 000	Kg
**Total methane production potential	184, 174, 375	M^3
Petroleum diesel oil equivalent	155, 074, 824	Litres
Electricity equivalent	1, 834, 376, 775	kWh
Firewood equivalent	239, 426, 688	Kg

** Extrapolated from: normalized methane yield at 1:1.7:1.2:1 inoculum-to-sisal waste to cow dung ratio = 0.301 m^3/Kg VS

CONCLUSIONS AND RECOMMENDATION

The results of this study reports for the first time the characteristics of sisal processing waste generated at Kilifi plantation, Kenya. Analysis indicates that both liquid and solid wastes have relatively high salt content and very little protein. It also indicate that, SLDW has a high content of fibres especially lignin, cellulose and hemicelluloses. This study has shown that anaerobic digestion of SLDR as well as SLDW is a feasible process and hence is a viable alternative for recovering energy in the form of biogas. Therefore, there is relatively large potential for value addition on the sisal waste by growing mushroom and subsequent biogas production. For effective application of mushroom growing and biogas technology; sisal waste must be available adequately and reliably. Increasing sisal plantation by, for example, reviving old sisal farms and promoting the involvement of out-growers can fulfil this. There is also need to diversify the uses of the produced biogas/energy to widen up the market margin for sisal biogas projects and thus attract investors. Several options can be considered in this respect such as use of biogas as fuel in vehicles and tractors, compressing biogas for domestic uses to replacing conventional fuels like kerosene or firewood (239, 426, 688 Kgs) this will allow for the conservation of environment. It therefore, increases its own value by the value of i.e., forest saved or planted. Piping biogas for domestic and industrial uses; increase the use of the recovered heat and enhancing local grid power supply.

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