Biochemical Methane Potential (BMP) of *Miscanthus Fuscus* for Anaerobic Digestion

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Abstract- *There is an increasing global demand for energy crops and animal manures for an eco-friendly and renewable energy to supplement fossil fuel, aid in heat and electricity production. In order to meet this demand, this study aimed at optimizing the anaerobic digestion of Miscanthus Fuscus for biogas production at mesophilic temperatures in a biochemical methane potential (BMP) test. Methane production was measured for 20 days in a 500mL schott bottles in a batch mode and controlled at 37 ± 1°C. Miscanthus Fuscus was characterized in the batch reactor to enable the inoculum activity and the biogas volume reported during the 20 days. The cumulative volume of biogas (L/day) for the five biodigesters labelled as sample IDs 1-5 is reported as 0.67, 1.16, 1.01, 0.57, and 1.17 L/day respectively. Highest methane yield was reported on the 16th day of the BMP test at 27% v/v of biogas produced.*

Index Terms- Anaerobic digestion, Biogas, Biochemical methane potential, *Miscanthus Fuscus*.

I. INTRODUCTION

With the ever-increasing energy consumption and the depletion of fossil resources, the footing for a shift towards sustainable production of biofuels and bioproducts such as biogas from renewable sources still remain a key demand[24]. Several studies have been carried out to find renewable energy sources that possess the potential of replacing fossil fuel[7]. Also, urbanization has led to an increase in landfills and it is estimated that by 2025, two-thirds of people will be living in the cities globally[27]. For decades, the synthesis of a renewable energy source as an alternative to non-renewable energy source has been evaluated, with energy being produced from biogas through anaerobic digestion process[4]. Biogas is a renewable fuel that consists of 60-70% methane, 20-30% carbon dioxide and other trace gases such as hydrogen sulfide. The gas produced, can be used to generate electricity and also in the production of combined heat and power generation using appropriate technologies[11].

The anaerobic digestion process from which biogas is produced basically involves four main stages as a result of the biodegradation of organic matter by a cluster of microorganisms[7]. The first stage which is the hydrolysis is the rate-determining step, where carbohydrates, proteins, and fats present in the is biomass converted to glucose, amino acids, and fatty acids respectively. The next stage, which is acidogenesis, involves the conversion of these products to volatile fatty acids by acidogenic bacteria. The volatile acid products are then converted to carbon dioxide, hydrogen and acetates by acetogenic bacteria then finally the carbon dioxide produced can react with the hydrogen present to produce methane or the acetates are broken down to by methanogenic bacteria to form methane and carbon dioxide with other trace compounds[21, 26].

The performance of a biogas plant can be evaluated by studying and monitoring the variation in parameters, which includes temperature, agitation, carbon-nitrogen ratio, organic loading rate, hydraulic retention time, etc. Meanwhile, sharp change in these parameters could adversely affect the biogas production process[22]. For higher efficiencies, these parameters should be varied within a desirable range to operate the biogas at optimum threshold. Anaerobic digestion under thermophilic temperature often yields higher biogas than mesophilic temperatures: higher temperatures favour higher methane production compared to lower temperatures[16]. Interestingly, anaerobes have been found to be most active at mesophilic than thermophilic temperatures as the latter tend to require higher heat input as investigated in this study[15].

The pH of a digestion slurry affects the growth of microbes during anaerobic digestion and thus the digester should be maintained within a desired range of 6.8-7.2 by feeding it at an optimum loading rate to obtain higher yield[25]. The level is reported not to remain constant throughout the process because of the various anaerobic digestion processes especially at the acidogenesis stage as various acids are produced the pH of the digestion slurry tend to increase after the acidogenesis stage[30]. A pH of 8.0 has also been observed to produce higher yield of biogas from biomass which is in contrast with the optimum pH for higher yield of biogas as predicted by (Budiyono et al., 2013)[3, 18]. Furthermore, it has been established that biogas production is much dependent on substrate loading rate, as methane yield has been found to increase with considerable reduction in loading rate[28]. This conflicts with an analysis with which co-digestion was evaluated at different organic loading rates (OLR) under low mixing conditions and a stable performance being obtained when the system was overloaded[6]. Thus, illustrating how overloading can easily lead to system failure [1].

Certain limitations such as process instability, process failure, poor methane yield, high hydraulic retention time of 30-50 days and reactor failures have limited the full exploitation of the anaerobic digestion process[17]. Although several efforts have been made in few decades, there still remain the need for researchers to seek for alternative processes to curb for these limitations to boost the efficacy of the biogas production. Processes such as co-digestion, low organic loading, pretreatment methods (for example, liquid hot water, acid hydrolysis, steam explosion, and alkaline hydrolysis), and the use of energy crops as feedstocks, have increased the efficacy of biogas production through anaerobic digestion[2, 20]. Recirculation of digested slurry (digestate which is enriched with microbes) back into the reactor and design modification of existing biogas plants are some of the ways to also improve the gas production in biogas plants[25].

Miscanthus Fuscus, one of three species known as elephant grass, is a South Asian grass species first described by William Roxburgh. This bamboo-like plant grows rapidly up to 3 meters high, generating a high yield of biomass with low ash content, suitable for use in electricity generation[29]. It is, however, a promising non-food crop yielding a high-quality lignocellulosic material which can be used in a number of ways, including energy and fiber production, thatching, and industrial use as in the case of this study[8]. *Miscanthus Fuscus* has been found to be suitable for biogas production and has a higher methane yield potential per unit area[14]. Research have proven that, *Miscanthus Fuscus* harvested before winter increases the yield and digestibility for anaerobic digestion[10].

This study seeks to focus on the production of biogas on Laboratory scale using the biochemical methane potential test with *Miscanthus Fuscus*, an energy crop under mesophilic anaerobic digestion.

II. MATERIALS AND METHODS

The biochemical methane potential test was carried out to determine the potential of the *Mischanthus Fuscus* (Fig.1) with cow dung.

Fig.1: Harvested Mischanthus *Fuscus*

Material Sampling

Miscanthus Fuscus was harvested from a local farm land at Adako Jachie in the Ashanti region of Ghana, and was used as the main feedstock for the biogas production. The feedstock was washed and dried to remove the unwanted particles. Furthermore, it was shredded and milled with a hammer miller (Fritsch Pulverisette 558, Germany) to obtain particle size of 10 mm. This was done to increase the surface area for adsorption during the anaerobic digestion process. A fresh cow dung used as inoculum was obtained from the cattle farm of Kwame Nkrumah University of Science and Technology, Department of Animal Science. The inoculum was kept in a sealed schott bottles, stored at 4°C, left to stand for 3 days before carrying on with further analysis.

Characterization of feedstock and Inoculum

The raw feedstock was characterized and analyzed for total solids, moisture content, volatile solids, and ash contents in accordance with the standard methods[23]. All procedures were carried out in the Laboratory using a precision balance (Kern PCB 3500-2, United Kingdom) for weighing the masses, a convection oven (VWR DRY-line oven, Pennsylvania) for drying feedstock and inoculum and a muffle furnace (Nabertherm, Germany) for ashing. The pH was measured by a pH meter (Thermo Scientific Orion star A121, United States of America). The experimental design of the feedstock and inoculum for the feeding each of the biodigesters is depicted in Table 1. Also, the pH recorded in each of the biodigesters after the 20 days is reported in the same table. Volatile fatty acids production rate is much higher than the methane production rate resulting in pH levels below the optimum range and can inhibit methanogens. This is because of their high level of sensitivity to acidic conditions[9]. After feeding the biodigesters at an optimal loading rate, the pH in each biodigester in this study was kept within the desired range of 6.7-7.0 as shown in Table 1. This is almost the same for what was recorded by Maile et al. (2016b) where $CaCO_3$ and NaOH was rather used to control the alkalinity during the anaerobic digestion[12].

Table 1: Experimental design for the feedstock and the Inoculum

Sample ID	Elephant grass(%RM)	Cow dung (%DM)	pH
1	100	0	6.78
2	0	100	7.05
3	50	50	7.08
4	25	75	7.01
5	75	25	6.89

Experimental setup and procedure

The total solids and volatile solids of the feedstocks and inoculum were pre-determined and used to prepare the digestion samples into the 500 mL schott bottles (with an effective 350mL volume). For each run, a headspace of 150 mL was left which was purged with nitrogen gas (N_2) to create the anaerobic environment within each of the biodigesters. The biodigesters were closed air-tight with rubber caps and incubated in a Laboratory incubator (Uniscope SM9052, United State of America) as shown in Fig.2. Since it is a batch system, it was made to run until digestion is complete.

Nutrients, in the form of trace metals are added in biodigesters to improve the efficiency and stability during the anaerobic digestion process in mono-digestion[17]. In this study, the trace metals, nitrogen, potassium, phosphorous, and iron were added to each biodigester to improve the efficiency and stability of the biodigester as employed in mono-digestion as depicted in Table 2. After stirring to ensure uniformity, the pH of each biodigester was measured and recorded within an optimum range of 6.7-7.1 as shown in Table 1. However, since the recorded pHs during the analysis were within the desired range as predicted by Sreekrishnan et al. (2004), no solvent was introduced in the biodigester for pH adjustment[25].

The composition of biogas was assessed by a batch biochemical potential (BMP) test at a mesophilic condition of 37±1°C for a retention time of 20 days for the overall analysis using a Biogas analyzer (Geotech Biogas 5000, United Kingdom). The anaerobic digestion system was designed to quantitatively determine the volume of biogas produced using a water displacement method and qualitatively for methane (CH_4), Carbon dioxide (CO_2) and trace amounts of hydrogen sulfide (H_2S).

Table 2: Composition of nutrient supplementation to each bio-digester

Name of compound	Elemental nutrient	Concentration (g/L)
Ammonium chloride	N	0.530
Potassium dihydrogen orthophosphate	K	0.270
Disodium hydrogen phosphate dihydrate	P	0.560
Iron (II) chloride tetrahydrate	Fe	0.020

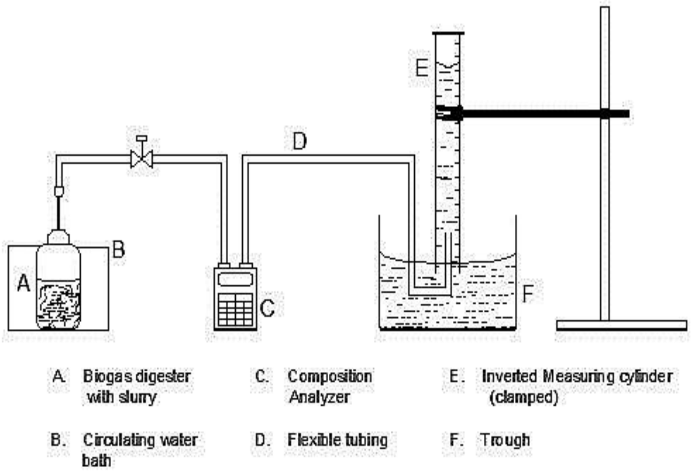

Fig. 2: Schematic flow diagram of the Biochemical Methane Potential Test

III. RESULTS AND DISCUSSION

Composition of Miscanthus Fuscus and Cow dung

The inoculum (cow dung reported as raw material) and the feedstock (Miscanthus Fuscus reported as dry matter) is characterised for the total solids, volatile solids, and ash composition is shown in Table 3 below. The results showed a great methane potential as a significant biodegradable fraction that do exist in the feedstock.

Table 3: Reported values for the characterization of the feedstock and Inoculum

Sample ID	Total solids (% RM)	Total solids (% DM)	Volatile solids (% RM)	Ash content (% DM)
1	8.945	91.055	88.945	11.055
2	10.215	89.785	10.215	89.785
3	8.135	91.865	8.135	91.865
4	8.615	91.385	89.9	10.1
5	9.84	90.16	84.56	15.44

*DM: dry matter; *RM: raw material

Effect of Biochemical Methane Production on the Biogas Production

Methane Production

The rate of methane production can be affected by factors such as the surface area or microorganisms to substrate ratio, microbial activity inside the biodigester, pH in the biodigester at any given time, and the solid retention time[19]. As shown in Fig. 3, the actual production of methane was observed after day 2. This could be due to the fact that the microorganisms needed to acclimatize to the set conditions such as temperature within the biodigesters. The sample ID 2 was also observed to yield the highest amount of methane after a sharp rise from day 4 to day 11 (12% v/v biogas) which may be due to maximal hydrolytic activity of the ferment. However, in all the five biodigesters, sample 1D 5 yielded the highest methane production on day 16 (27% v/v biogas) as the methane production started on day 4 followed by sample ID 2. The yield of methane in the rest of the biodigesters was not appreciable throughout the anaerobic digestion process. This could be attributed to unfavourable anaerobic digestion conditions within the biodigesters which yielded low methane.

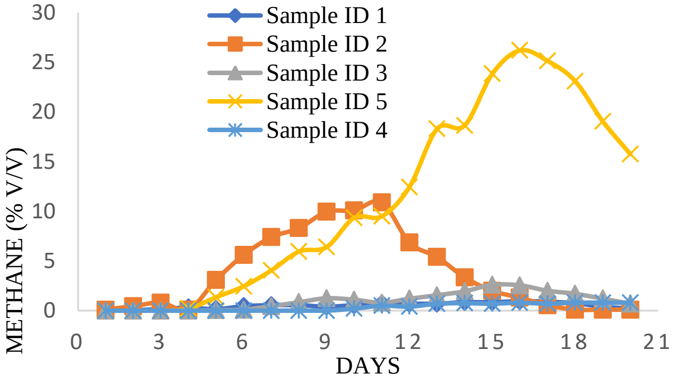

Fig.3: Cumulative methane (CH_4) yield from the different bio-digesters

CO_2 Production

Biogas, a renewable fuel consists of 60-70% methane, 20-30% carbon dioxide and other trace gases such as hydrogen sulfide[11]. However, Carbon dioxide remain the second abundant gas after methane in biogas and thus a reduction of methane was observed to cause a rise in the yield of carbon dioxide as shown in Fig. 3 and 4 comparatively. It was observed in this study that the amount of carbon dioxide produced was higher as compared to that of the methane in all the biodigesters. However, lower yield of methane has been attributed to higher carbon dioxide in biogas from previous studies. Nonetheless, recent studies have warranted the use of concentrated alkaline compounds such as NaOH for the CO_2 dissolution[13]. The highest carbon dioxide yield was reported on day 3 by sample ID 1 as depicted in Fig.4.

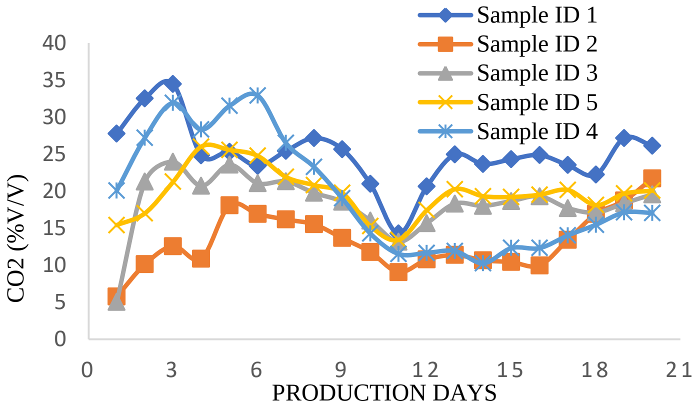

Fig.4: Cumulative carbon dioxide (CO_2) yield from the different bio- digesters

H_2S Production

H_2S was however observed to be predominant in the biogas produced and a likelihood to contribute to the lower yield in the methane production with sample ID 1 recording the highest on day 2 (90% v/v biogas). H_2S in sample ID 4 was observed to be higher in both day 3 (60% v/v biogas) and day 16 (60% v/v biogas) which could be attributed to a favourable sulphur producing conditions by the microorganisms during this stage of the anaerobic digestion process as shown in Fig. 5 below.

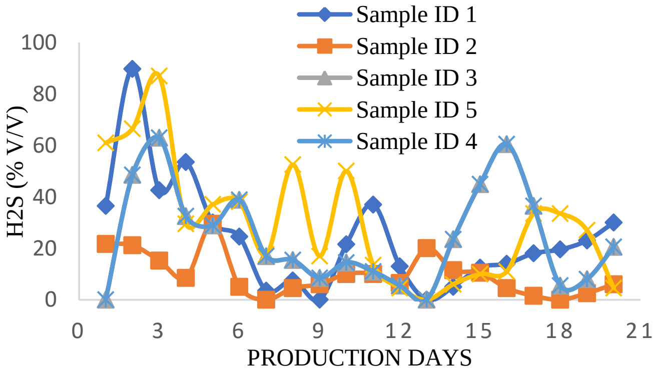

Fig.5. Cumulative hydrogen sulphide (H_2S) yield from the different biodigesters

The Water Displacement Method for Biogas Production

This method has been developed to measure the volume of biogas produced and widely utilized to determine biogas yield in anaerobic digestion process. This method has for the past decade been used for the measurement of the volume of biogas produced from reactors especially at Laboratory scale[22]. Since biogas has a lower density than water and insoluble in water, the downward displacement was adopted as the evolved gas was observed to be displaced at the topmost portion of the inverted glass tube, hence its volume measurement. However, the amount of water displaced is thus found to be equal to the biogas generated. In this study however, the cumulative volume of biogas for the five biodigesters labelled as sample IDs 1-5 was reported as 0.67, 1.16, 1.01, 0.57, and 1.17 L/day respectively as in Fig.6 below.

In addition, the highest volume of biogas produced was recorded by sample ID 5. This gives an indication that the volume of biogas produced is directly proportional to the methane produced.

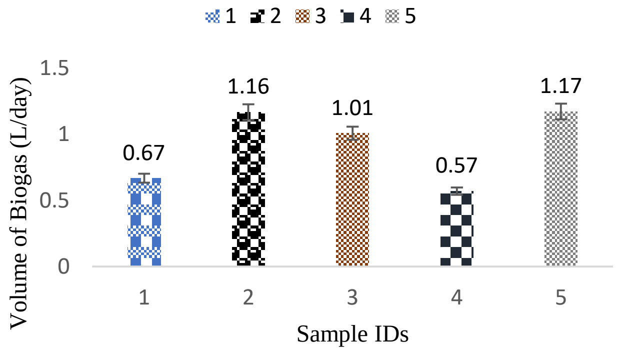

Fig.7. Overall biogas production from the water displacement method

IV. CONCLUSION

The biochemical methane potential (BMP) test of *Miscanthus Fuscus* with cow dung was investigated as little is known in literature about the production of this feedstock at Laboratory scale to produce biogas. The volume of the BMP test was determined for the five biodigesters at an average of 0.916 L/day of biogas production. The pH was also observed within the optimum range of 6.7-7.1 and thus no need for pH adjustment. Also, anaerobic digestion in this study at mesophilic temperatures was found to be a viable process for biogas production and thus warranted by all researchers both for its production at larger scale and also a look at the activity of inhibitors. The highest methane content was found to be 27% v/v of biogas yield and was observed to be lower as compared to the carbon dioxide yield. Thus, a pretreatment technique and carbon dioxide purification method is warranted to all researchers. Therefore, Miscanthus Fuscus has the potential to produce biomethane, which can be used to ease the dependency on fossil fuel derived energy and as an alternative energy source for combined heat and energy, which is eco-friendly.

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REFERENCES

[1] Abbasi, T., Tauseef, S., Abbasi, S. 2012. Anaerobic digestion for global warming control and energy generation—an overview. *Renewable and Sustainable Energy Reviews*, **16**(5), 3228-3242.

[2] Alvira, P., Tomás-Pejó, E., Ballesteros, M., Negro, M. 2010. Pretreatment technologies for an efficient bioethanol production process based on enzymatic hydrolysis: a review. *Bioresource technology*, **101**(13), 4851-4861.

[3] Budiyono, B., Syaichurrozi, I., Sumardiono, S. 2013. Biogas production from bioethanol waste: the effect of pH and urea addition to biogas production rate. *Waste Technology*, **1**(1), 1-5.

[4] El-Mashad, H.M., Zhang, R. 2010. Biogas production from co-digestion of dairy manure and food waste. *Bioresource technology*, **101**(11), 4021-4028.

[5] Eliyan, C. 2007. Anaerobic digestion of municipal solid waste in thermophilic continuous operation. in: *School of Environment, Resource and Development*, Vol. Master of Science, Asian School of Technology.

[6] Gomez, X., Cuetos, M., Cara, J., Morán, A., Garcia, A. 2006. Anaerobic co-digestion of primary sludge and the fruit and vegetable fraction of the municipal solid wastes: conditions for mixing and evaluation of the organic loading rate. *Renewable energy*, **31**(12), 2017-2024.

[7] Gu, H., Zhang, K., Wang, Y., Huang, Y., Hewitt, N., Roskilly, A.P. 2013. Waste biomass from production process co-firing with coal in a steam boiler to reduce fossil fuel consumption: A case study. *Journal of Energy Chemistry*, **22**(3), 413-419.

[8] Jones, M.B., Walsh, M. 2001. Miscanthus for Energy and Fibre, Earthscan London, United Kingdom.

[9] Khanal, S.K. 2011. Anaerobic biotechnology for bioenergy production: principles and applications. John Wiley & Sons.

[10] Kiesel, A., Lewandowski, I. 2017. Miscanthus as biogas substrate–Cutting tolerance and potential for anaerobic digestion. *Gcb Bioenergy*, **9**(1), 153-167.

[11] Maile, I., Muzenda, E., Mbohwa, C. 2016a. Biochemical methane potential of OFMSW for City of Johannesburg.

[12] Maile, I.O., Muzenda, E., Mbohwa, C. 2016b. BiochemicalMethane Potential of OFMSW for City of Johannesburg. San Francisco on 26-28 October, 2016.

[13] Maile, O.I., Muzenda, E., Tesfagiorgis, H. 2017. chemical absorption of carbon dioxide in biogas purification. in: *Procedia Manufacturing*, Vol. 7, pp. 639-646.

[14] Mayer, F., Gerin, P.A., Noo, A., Lemaigre, S., Stilmant, D., Schmit, T., Leclech, N., Ruelle, L., Gennen, J., von Francken-Welz, H. 2014. Assessment of energy crops alternative to maize for biogas production in the Greater Region. *Bioresource technology*, **166**, 358-367.

[15] Mital, K. 1997. Biogas systems: policies, progress and prospects. Taylor & Francis.

[16] Muvhiiwa, R.F., Matambo, T.S., Chafa, P.M., Chikowore, N., Chitsiga, T., Low, M. 2016. Effect of temperature and pH on biogas production from cow dung and dog faeces. *Africa Insight*, **45**(4), 167-181.

[17] Nges, I.A. 2012. Anaerobic digestion of crop and waste biomass: Impact of feedstock characteristics on process performance, Vol. Doctoral, Luund University (Media-Tryck).

[18] Ogbonda, K.H., Aminigo, R.E., Abu, G.O. 2007. Influence of temperature and pH on biomass production and protein biosynthesis in a putative Spirulina sp. *Bioresource Technology*, **98**(11), 2207-2211.

[19] Raposo, F., Fernández-Cegrí, V., De la Rubia, M., Borja, R., Béline, F., Cavinato, C., Demirer, G., Fernández, B., Fernández-Polanco, M., Frigon, J. 2011. Biochemical methane potential (BMP) of solid organic substrates: evaluation of anaerobic biodegradability using data from an international interlaboratory study. *Journal of Chemical Technology and Biotechnology*, **86**(8), 1088-1098.

[20] Ribeiro, F.R., Passos, F., Gurgel, L.V.A., Baêta, B.E.L., de Aquino, S.F. 2017. Anaerobic digestion of hemicellulose hydrolysate produced after hydrothermal pretreatment of sugarcane bagasse in UASB reactor. *Science of the Total Environment*, **584**, 1108-1113.

[21] Saady, N.M.C., Massé, D.I. 2015. Impact of organic loading rate on psychrophilic anaerobic digestion of solid dairy manure. *Energies*, **8**(3), 1990-2007.

[22] Simo, W.S.F., Jong, N.E., Kapseu, C. 2016. Improving Biogas Production of Sugarcane Bagasse by Hydrothermal Pretreatment. *Chemical and Biomolecular Engineering*, **1**(3), 21-25.

[23] Sluiter, A., Hames, B., Ruiz, R., Scarlata, C., Sluiter, J., Templeton, D., Crocker, D. 2008. Determination of structural carbohydrates and lignin in biomass. *Laboratory analytical procedure*, **1617**, 1-16.

[24] Sørensen, A., Lübeck, M., Lübeck, P.S., Ahring, B.K. 2013. Fungal beta-glucosidases: a bottleneck in industrial use of lignocellulosic materials. *Biomolecules*, **3**(3), 612-631.

[25] Sreekrishnan, T., Kohli, S., Rana, V. 2004. Enhancement of biogas production from solid substrates using different techniques—a review. *Bioresource technology*, **95**(1), 1-10.

[26] Sun, Y., Cheng, J. 2002. Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource technology*, **83**(1), 1-11.

[27] Troschinetz, A.M., Mihelcic, J.R. 2009. Sustainable recycling of municipal solid waste in developing countries. *Waste management*, **29**(2), 915-923.

[28] Vartak, D., Engler, C., Ricke, S., McFarland, M. 1997. Organic loading rate and bioaugmentation effects in psychrophilic anaerobic digestion of dairy manure. *Paper-American Society of Agricultural Engineers*(974051).

[29] Wagner, M., Kiesel, A., Hastings, A., Iqbal, Y., Lewandowski, I. 2017. Novel miscanthus germplasm-based value chains: A Life Cycle Assessment. *Frontiers in Plant Science*, **8**, 990.

[30] Zhang, R., El-Mashd, H., Hartman, K., Wang, F., Liu, G., Choate, C., Gamble, P. 2007. Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technology*, **98**, 929-935.

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