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A Comparative Study for Biogas Production using Pressmud, Bagasse and Paddy Straw

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ABSTRACT

The present work investigates the biogas production from pressmud (PM), bagasse (BG) and paddy straw (PS) alone and in combination to examine the possibility of utilizing these agro-residues for higher and better-quality biogas production. A setup composed of aspirator bottles was used to produce biogas in an open area without maintaining temperature. The biogas produced was measured using the water displacement method. Among all the test runs, the combination of pressmud, bagasse and paddy straw in a ratio of 1:1:2 produced over all 222 L of biogas as compared of 188 L using cattle dung as control from 1 kg of dry weight of biomass/cattle dung. Whereas, the quality biogas (more than 30% methane content) suitable for direct burning for cooking purpose was produced 191 L with PM:BG:PS::1:1:2 as compared to 158 L in the control, and the time required to reach 30% methane content was 24 days with PM:BG:PS::1:1:2 as compared to 30 days in control. It was found that PS and BG alone are not suitable for biogas production though the combination of PM, BG and PS could produce higher amounts of biogas of good quality in a short period of time.

Keywords Biogas, Paddy straw, Pressmud, Bagasse, Methane content.

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INTRODUCTION

Our natural resources are under considerable strain considering India has about 2.4% of the world's area and 4.2% of its water resources, but supports about 17.6% of its population (NPMCR 2014). Our main challenge is to provide food grains for a growing population, while ensuring that our natural resources are sustained. A large volume of residue is generated by the harvesting of various crops both on and off the field. Approximately 500 Mt of crop residues are generated annually in India, according to the Ministry of New and Renewable Energy. Uttar Pradesh (60 Mt) produces the highest amount of crop residues, followed by Punjab (51 Mt) and Maharashtra (46 Mt). The majority of crop residues originate from cereals (352 Mt), followed by fibers (66 Mt), oilseeds (29

Mt), pulses (13 Mt) and sugarcane (12 Mt). Among the total crop residues, cereal crops (rice, wheat, maize, millets) contribute 70%, while rice alone contributes 34%. The residue generated by sugarcane consists of tops and leaves, constituting 12 Mt or 2% of the crop residues in India.

During 2019-20, India produced 118.87 Mt of milled rice, placing it second in the world. The paddy straw resulting from the rice production is a major by-product. A potential feedstock for biogas production could be paddy straw, resulting in the production of significant amounts of bioenergy and aiding in the management of crop residues. On the other hand, sugarcane is mostly used as a feedstock for the sugar and ethanol industries. Large-scale distilleries have recently been integrated with sugar mills to facilitate the efficient utilization of molasses, a second by-product of the sugar industry. Additionally, such industries generate large quantities of organic wastes, such as leaves and mulches in the sugarcane fields after harvesting, bagasse, pressmud, and spent wash (Partha and Sivasubramanian, 2006). Sugar producers use bagasse as a fuel source for their furnaces in order to meet a portion of their heating requirements. Sugar industries also produce pressmud, a dark brownish, amorphous solid residue that is produced after clarification of sugarcane juice (Gupta *et al.* 2011). Pressmud represents 3% of the total sugarcane processed. Pressmud is generally sold either as partially converted compost for agricultural and horticultural applications as manure or discarded in the open field (Rasul *et al.* 1999, Saravanane and Sivasabkaran 2005).

Due to the generation of large quantities of agricultural residues and the use of harvesters, leftovers in the field is an ongoing problem. In order to prepare the land for the next crop, farmers need to remove this residue as soon as possible. Managing leftover crop residues properly requires extra effort, money, manpower, and time. To avoid all these problems, farmers decided to burn the stubble in the field itself. This contributes to the degradation of soil health as well as air pollution. The burning of stubble in situ results in the loss of nutrients as well as resources. Along with the deterioration of the air quality, burning stubbles leads to soil nutrient loss consisting of organic carbon of 3850 kg, nitrogen of 59 kg, phosphorus of 20 kg, and potassium of 34 kg, as well as releasing high levels of air pollutants such as COx, CH4, NOx, SOx, and particulate matter PM10 and PM2.5 (Kumar *et al.* 2015, Porichha *et al*. 2021). As the crop residues vary, so does the pollution intensity. For example, the PM2.5 emissions (g/kg) from *in situ* burning of various crops are as follows: sugarcane (12.2) > maize (11.2) > cotton (9.8) > rice (9.3) > wheat (8.5) (TERI 2019).

When crop residues are burned in the field, harmful gases such as CO, NO, and SOx are released into the atmosphere. This causes significant air pollution, particularly during the winter months. These gases affect human health and the environment, as well as degrading farm soil. Studies have shown that burning rice and wheat residues on the field results in a loss of about 80% nitrogen, 25% phosphorus, 21 % potassium and 40 to 60% soil sulfur (Datta *et al*. 2020, Mandal *et al.* 2004).

Developing alternative sustainable uses for crop residue is therefore urgently needed. Among the most desirable applications of crop residue are the production of bioenergy/biofuels, as well as value added products such as bio-composites, platform chemicals. By developing economic, sustainable technologies or using different technologies, these crop residues can be processed into biomass pellets, briquettes, biogas, bioethanol, and biobutanol. Furthermore, this may benefit farmers economically.

Throughout this study, efforts have been made to maximize the use of paddy straw, bagasse, and pressmud to produce biogas, an environmentally friendly and clean fuel for the household. The use of biogas could replace conventional energy sources such as fossil fuels, LPG, and CNG, which have been proven to be harmful for the environment and are soon to be depleted (Yadvika *et al*. 2004). Considering that lignocellulosic biomasses, such as crop residue, are a cheap and renewable resource, they could be very well used for the production of biogas. The production of biogas involves anaerobic digestion using a consortium of microorganisms, consisting of four independent steps: Hydrolysis, acidogenesis, acetogenesis, and methanation. It is pertinent to note that each of these steps is carried out by a specific type of microorganism, for example, the hydrolysis of carbohydrates, proteins, and lipid polymers into their monomers requires microorganisms that produce enzymes, such as cellulases, hemicellulases, proteinases, proteases, and lipases, to catalyze the hydrolysis. During the next stage of acidification, microorganisms are required to convert the monomers into volatile fatty acids (VFA), NH_3, CO_2, and H_2. Later on, during acetogenesis, VFAs are transformed into acetate, hydrogen, and carbon dioxide by acetogens. Acetogens work in syntrophic association with sulfate-reducing or methanogenic bacteria. During the final stage of biogas production, methanogens convert acetate, hydrogen, and carbon dioxide (CO_2) into methane and carbon dioxide (biogas) (Meher and Biosciences 1993,Singh *et al*. 2019).

This study investigated the potential for using readily available and underutilized agricultural products such as paddy straw, pressmud, and bagasse as feedstocks for biogas production. Organic matter is abundant in these feedstocks, making them potential bioresources for biogas production. Currently, no such study has been found comparing the biomethanation potential of paddy straw, pressmud, and bagasse.

MATERIALS AND METHODS

All the experiments were conducted at the laboratory of Department of Renewable and Bio-energy Engineering, COAE and T, CCS HAU, Hisar.

Collection of samples and physical processing

In this study, paddy straw was collected from a farmer's field located in Hisar, Haryana, while pressmud and bagasse came from a sugar mill located in Kaithal, Haryana. Cattle dung used as control run was collected from the animal farm of College of Animal Sciences, LUVAS, Hisar, Haryana. As particle size has a significant influence on biogas production, (Mshandete *et al*. 2006, Rodriguez *et al.* 2017) bagasse and paddy straw were shredded to a size range of 5-25 mm with an average of 15 mm using a solar powered biomass shredder.

Analysis of substrates

Analyses of pressmud, bagasse, paddy straw and cattle dung were performed in triplicate and average values were reported. A 5 g sample of each feedstock was dried in a muffle furnace for 24 hrs at 105 °C. Thereafter, the weight of the sample as well as the crucible were recorded every hour until three consecutive measurements were constant. This constant weight represented the total solids (TS). This weight difference between the sample and the TS represents the moisture content.

The TS and moisture contents (%) were calculated as per Eqs. (1) and (2), as below:

$$\text{TS (\%)} = \left(\frac{\text{TS}}{\text{weight of sample}}\right) \times 100 \qquad (1)$$

$$\text{Moisture (\%)} = 100 - \text{TS (\%)} \qquad (2)$$

Following drying, the samples were heated in a muffle furnace at 550°C for 3 hrs, then cooled in a desiccator and weighed. The constant weight thus obtained represented the ash content. Volatile solids (VS) are represented by the weight difference between the ash and the TS. In accordance with Eqs. 3 and 4, the VS and ash contents (%) were calculated.

$$VS\text{ (\%)} = \frac{VS}{Weight\ of\ sample} \times 100 \qquad (3)$$

$$Ash\text{ (\%)} = 100 - (Moisture, \% + VS, \%) \qquad (4)$$

Nitrogen (N), phosphorus (P) and potassium (K) of pressmud, bagasse, paddy straw and cattle dung were estimated by following the standard procedures (Bremner 1960, JOHN 1970, Antil *et al.* 2002, respectively). The various constituents of feedstock like cellulose, hemicellulose, lignin and volatile fatty acid were also estimated using standard procedures (Horwitz 2000 and AOAC 2000). The composition of biogas viz., methane, carbon dioxide were measured with a biogas 5000 (Geotech) analyzer. The daily biogas production was measured using the water displacement method.

Experimental set-up

For the biogas production experiments the setup consisting of three aspirator bottles was utilized for

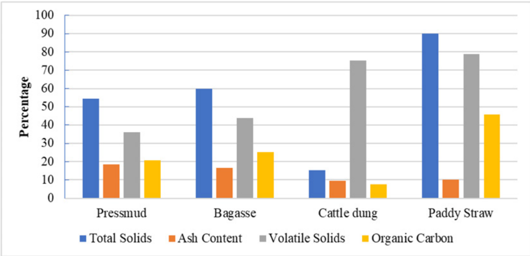

Fig. 1. Proximate analysis of PM, BG, CW and PS.

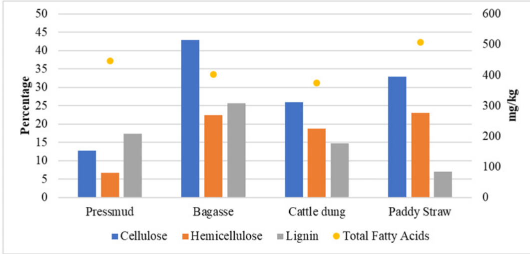

Fig. 2. Cellulose, hemicellulose, lignin and TVFs of raw materials.

each treatment. The 20 L aspirator bottle was used as a biogas reactor and two 5 L aspirator bottles, one used as a water reservoir and another as a water collector for displaced water. The biogas reactor was sealed with cork having two openings (one for biogas sampling and another for biogas transfer from reactor to water reservoir) whereas the water reservoir bottle was also sealed with cork.

The experiment included three feedstocks: Pressmud (T1), bagasse (T2), and a combination of pressmud, bagasse, and paddy straw in ratios of 1:1:1 (T3) and 1:1:2 (T4), with a control as cattle dung (T5). The experiments were conducted using 10% total solid with total slurry volume of 10 L. The biogas experiments were started by inoculating the feedstock slurry with 1 kg active inoculum collected from the Janta type biogas plant situated at CCS HAU, Hisar. Experiments were conducted until biogas production and methane content started declining. Initial and final pH values of the substrate and digested slurry were measured and reported as 6-7 and 8-8.5, respectively.

RESULTS AND DISCUSSION

Proximate analysis

All three substrates were found to have a range of total solids (TS) between 89.91 % and 15.22 % with paddy straw exhibiting the highest TS and cattle dung the lowest, which is in agreement with Xavier *et al.* (2015). Ash content was found to be between 18.55 % and 10.21%, where pressmud had the highest content, and cattle dung had the least. Volatile solids (VS) are in the range of 78.7% to 36.0%. Paddy straws have the highest VS, while pressmud have the lowest. Paddy straw and cattle dung have higher VS compared to other substrates, making them excellent biogasification substrates. The organic carbon (OC) content was 45.65 - 7.71 %, with the highest being paddy straw and the least being cattle dung.

Ultimate analysis to quantify cellulose, hemicellulose, lignin and total volatile fatty acids of all feedstock's before anaerobic digestion was conducted, the results are shown in Fig. 2. The maximum cellulose and lignin 42.98% and 25.61% were estimated in bagasse. Whereas maximum hollocelluose (cellulose and hemicellulose) approx. 65.5% which was also found maximum in bagasse followed by paddy straw, cattle dung and pressmud viz., about 56%, 45% and 20% respectively, representing the potential of biogas production. The hemicellulose content was found maximum in paddy straw followed by bagasse, cattle dung and pressmud i.e., 23.05%, 22.5%, 18.8% and 6.8% respectively.

The nitrogen, phosphorus and potassium were also estimated and are reported in Fig. 3. The

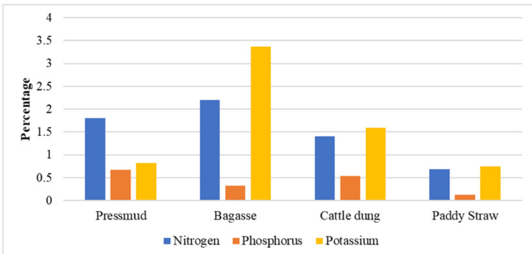

Fig. 3. Percentage share of nitrogen, phosphorus and potassium of total solids for substrates.

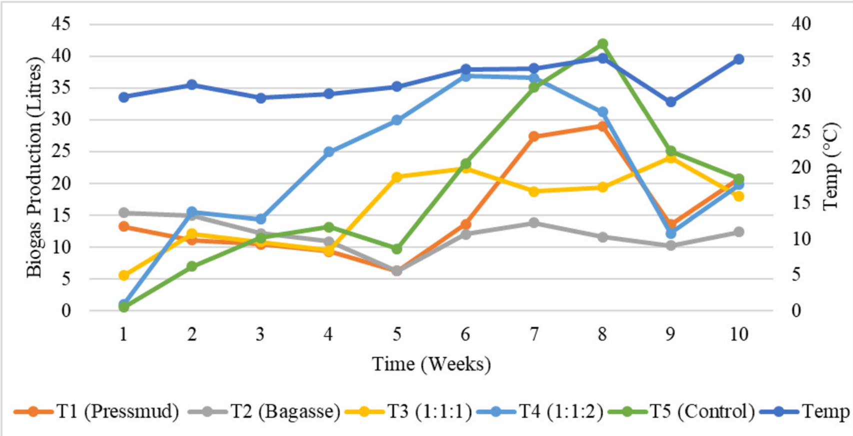

Fig. 4. Average weekly variation of biogas production with temperature.

maximum nitrogen was found in bagasse i.e. 2.2% followed by pressmud 1.8%, cattle dung 1.4% and paddy straw 0.7% whereas potassium was also found maximum in bagasse i.e., approx. 3.4% followed by cattle dung 1.6%, pressmud 0.8% and paddy straw 0.75%. The phosphorous was estimated maximum in pressmud i.e., 0.67% followed by cattle dung 0.54%, bagasse 0.32% and paddy straw 0.12%.

Biogas production

Weekly average of biogas production and ambient temperature was estimated and reported in the Fig. 4. Whereas as weekly average methane content along with temperature is shown in Fig. 5. All the biogas production experiments were conducted in open space without controlling the temperature. It was observed that change in temperature adversely affected the biogas production while the composition of the biogas was not significantly affected. The experiment lasted for 10 weeks. The decline in biogas production was observed after 8^{th} week of incubation from the day of starting the experiment. During the 9^{th} week there was 2-3 rainy days which had also impacted the biogas production which can also be observed from the Fig. 4. Total biogas produced in T1, T2, T3 and T4 were found to be 154 L, 119 L, 148 L, 222 L as compared to 188 L in control. From the results it was observed that

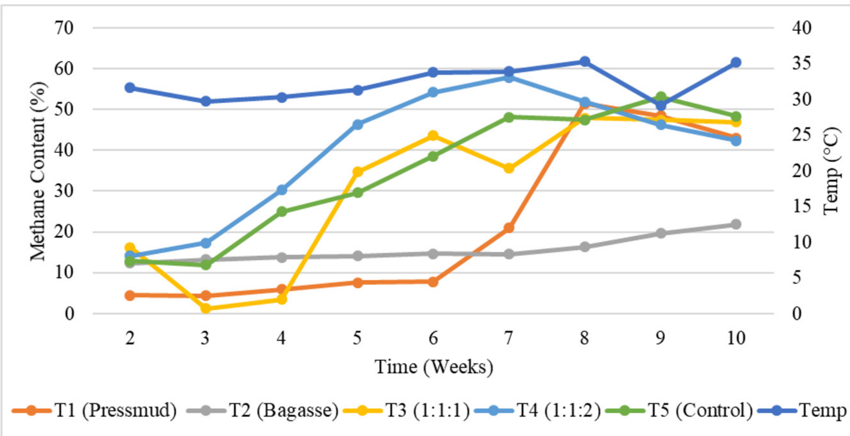

Fig. 5. Weekly variation of methane content with temperature.

pressmud: Bagasse: Paddy straw in a ratio of 1:1:2 generated highest biogas during a period of 10 weeks. It was also observed that combination pressmud, bagasse and paddy straw can produce much higher biogas as compared to that of control (cattle dung).

Biogas containing more than 30% methane content was also analyzed as it can be used for cooking purposes. The amount of biogas with more than 30% methane content was found 83 L, 112 L and 191 L in T1, T3 and T4, respectively after 48, 30 and 24 days as compared to 158 L in T5 (control) after 30 days of digestion. It is also evident from the results that the combination of pressmud: Bagasse: Paddy straw in a ratio of 1:1:2 had produced approx. 21% higher biogas (methane content > 30%) as compared to control with cattle dung with higher productivity. The treatment T2 was not able to reach 30% methane content during the experimentation period.

CONCLUSION

The study explored the potential of pressmud and bagasse and their combination with paddy straw as a substrate for biogas production potential. The study concludes that the combination of pressmud, bagasse and paddy straw can produce higher amounts of biogas than pressmud, bagasse and cattle dung alone.

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