



RESEARCH ARTICLE

Enhancing the biogas generation potential of Cumbu Napier grass through hydrothermal pretreatment

P Vijayakumary¹, Gitanjali J^{1,2*}, Rathinasamy P D^{1*}, Sriramajayam S³ & Desikan R¹

¹Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

²School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh, Scotland, EH10 5DT UK

³V O Chidambaranar Agricultural College and Research Institute, Tamil Nadu Agricultural University, Killikulam - 628 252, Tamil Nadu, India

*Correspondence email - jogitanjali@gmail.com; parimaladevi@tnau.ac.in

Received: 02 December 2025; Accepted: 09 March 2026; Available online: Version 1.0: 20 April 2026

Cite this article: Vijayakumary P, Gitanjali J, Rathinasamy PD, Sriramajayam S, Desikan R. Enhancing the biogas generation potential of Cumbu Napier grass through hydrothermal pretreatment. Plant Science Today. 2026; 13(sp2): 1-10. <https://doi.org/10.14719/pst.13027>

Abstract

This study aims to investigate the feasibility of hydrothermal pretreatment of cumbu napier grass for biochemical methane production. The hydrothermal pretreatment of the cumbu napier grass was carried out with 10 % total solids loading rate at various pressures (1, 5 and 10 bar) to disrupt the lignin, hemicellulose and cellulose bonding. The hydrothermal pretreated cumbu napier grass is mixed with cow dung at different ratios, such as (1:0, 3:1, 1:1 and 1:3). The study evaluates the hydrothermal pretreatment effectiveness of cumbu napier grass treated at 10 bar and mixed with an equal ratio of cow dung, resulting in the highest biogas yield of 18.64 L/kg with 44 to 56 % methane content. Also, this pretreatment condition confirmed high total solids (66.00 %), cellulose (79.64 %), hemicellulose (67.20 %) and lignin (56.40 %) destruction efficiency. Additionally, the FT-IR analysis and SEM analysis results indicated structural modification in the pretreated biomass, in turn enhancing the biodigestibility and confirmed the best approach to convert waste to energy in a sustainable way with a 3-year payback for a 1000 kg/day biodigester.

Keywords: anaerobic digestion; biodegradability; co-digestion; hydrothermal pretreatment; lignin destruction

Introduction

Lignocellulosic biomass can be used as a substrate to replace the food competitive feedstock in biogas generation (1, 2). The existing research is on optimising the substrate ratios to increase the biogas yield from lignocellulosic biomass. A critical gap exists in pretreatment studies, quality of biogas and biodigested slurry, co-digestion of cow dung with biomass and field-scale evaluation. Organic matter like agro-residues, slurry, food processing wastes and animal dung are the substrates used in the biomethanation process (3). The gross energy yield of biomass per hectare is a main focus to evaluate the performance of agricultural biomass for biogas generation (4). A variety of microbes is used to break down substrates into biogas in anaerobic condition is termed biomethanation or anaerobic digestion process (5, 6). It is an energy-efficient method and addresses the issues of waste management, nutrient recycling, bioenergy and sustainable agriculture (7). The biochemical composition of lignocellulosic biomass, namely cellulose, hemicellulose and lignin, affects its biodegradability in the biomethanation process (8). The biogas from the biomethanation process is employed in cogeneration units to produce heat and electricity. Alternatively, this biogas can be converted into biomethane by removal of CO₂, H₂O and H₂S gases and used as fuel for transportation or fed into the natural gas pipeline network (9). Biodigestate or biodigested slurry is a byproduct that comes after biodigestion of the biomethanation process, which is an alternative to fertiliser to use as manure (10).

The cumbu napier grass (*Pennisetum purpureum* × *Pennisetum americanum*) is a non-competitive substrate envisioned for a long-lasting substrate for biogas generation in the biomethanation process (11). It is a perennial crop and can be harvested more than four times annually, yielding about 45 tons of biomass/hectare /year. This grass is used primarily as feed for livestock to increase the milk yield. It can be a good substrate as a lignocellulosic biomass for biogas generation (12). Delayed harvest results in plenty of unutilized grass, which can be used as a substrate in biogas generation due to the large demand for biogas (13, 14). Thus, cumbu napier grass will be an attractive choice for the biomethanation process to produce sustainable energy along with nature conservation and rural development. Even though it lacks an assessment of its technical feasibility and to enhance the biogas yield.

In order to ease the biomethanation of lignocellulosic biomass, its structure is to be disrupted via a pretreatment process (15, 16). Because lignocellulosic biomass is resilient in being digested by microbes, it results in low biogas yield (17). There are several researches proved that dissolving lignin bonds will increase the biogas yield by increasing the microbial access to cellulose and hemicellulose of the substrate (18–21). The most explored pretreatment methods are physical, chemical and biological methods. Therefore, lignocellulosic biomass is to be pretreated to biochemical structural bonds to increase the surface area (22, 23). The biomass can be treated with acids, namely HCl, H₂SO₄, HNO₃, H₃PO₄ and CH₃COOH, or alkali, namely NaOH, Ca(OH)₂, NH₃ and

H₂O₂ to delignify biomass (24–28). Despite the encouraging outcomes of chemical pretreatment, there are still issues with these processes, including high costs, inhibitor production and chemical wastes (29). Physical pretreatment, on the other hand, like size reduction, is easy to implement, works well and pollutes the environment less. A higher porosity can enhance biomass capacity to decompose (30, 31). Water influences increased porosity; it enters the biomass fibre matrix's pores to increase pore volume, which further expands the solid structure (32). Using this mechanism, hydration pretreatment by soaking solid biomass in an aqueous solution or a hydration medium can boost biomass porosity and, consequently, the availability of microorganisms to biomass during biomethanation. The biodegradability of lignocellulosic biomass was enhanced by these acids (33). Thermal pretreatment, which is done at temperatures between 50 and 240 °C, is said to be one of the easiest and most effective techniques that can be used on an industrial scale. In addition to increasing the biomass swelling and accessible surface area, thermal pretreatment also made its chemical composition more soluble (34). On the other hand, there is meagre information on hydrothermal pretreatment for the biogas generation. Thus, the effect of hydrothermal pretreatment of cumbu napier grass is examined to determine its biodegradability and biogas yield.

Materials and Methods

The characterisation of selected lignocellulosic biomass is necessary to study its composition for its bioconversion to bioenergy (35). The cumbu napier grass was collected from the Department of Forage Crops, Tamil Nadu Agricultural University, Coimbatore. The following methods are used to determine the composition of selected lignocellulosic biomass, viz., cumbu napier grass. Moisture content of the sample was measured by placing a known weight of the sample at 103 ± 2 °C until it reached its constant weight as per ASTM D 3173-87 method. The total solids content of the sample was estimated by subtracting the moisture content from 100. The volatile content was determined by heating the moisture-driven sample to 650 °C for 10 min in an oxygen-depleted environment (ASTM D 3175-89). The ash content was found by heating the moisture-driven sample to 750 °C for three hours (ASTM D 3174-89). The material that was left over after volatile and ash content was determined as fixed carbon. The elemental composition of agricultural crop residues reveals the Carbon (C), Hydrogen (H), Nitrogen (N), Sulphur (S) and Oxygen (O) content in the sample. The Elemental Analyser was used to determine the percentage representation of the elements in the biomass (ASTM D-5291). The percentage of cellulose, hemicellulose and lignin was determined using the NREL method (36). Pretreatment of cumbu napier grass was carried out by shredding the grass sample and treating it in a 5 L capacity hydrothermal reactor (Amar Equipment Make) at 10 % total solids content and varied pressure (1, 5 and 10 bar) corresponding to their respective temperature, followed by cooling to ambient temperature for effective degradation of lignin. To study the effectiveness of biomass pretreatment, SEM and FT-IR analysis were carried out. SEM (Scanning Electron Microscopy) was used to determine the structure of a raw and treated sample. The FT-IR (Fourier Transform Infrared Spectroscopy) analysis, both before and after the hydrothermal process pretreatment at the wavelength range of 400–4000 cm⁻¹, was studied to understand the

changes in functional groups of biomass in Fourier transmission infrared microscopy (37).

A laboratory-scale biomethanation experiment was conducted in 125 ml glass bottles with raw and pretreated cumbu napier grass combined with cow dung at 10 % Total solids content to study the biogas potential assessment. The biogas yield and methane concentration were recorded for the retention period of 60 days. The estimation of lignin, hemicellulose and cellulose of pre- and post-biomethanation studies was conducted to calculate their destruction efficiency (38).

Pretreated biomass samples were mixed with cow dung at ratios of 1:0, 3:1, 1:1 and 1:3 with 10 % Total solids Content and filled in an air-tightened glass bottle (39). The biochemical liquid concentration in biogas will be assessed to assess the effectiveness of biodegradability through GC-MS (Gas Chromatography-Mass Spectrometry) analysis (40). In order to confirm the biogas' potential as a biofertilizer with Carbon, Nitrogen and Carbon: Nitrogen (CN) ratios, nutrient analysis was also carried out (41).

Results and Discussion

The collected cumbu napier grass was physically treated (size reduced) to less than 1 cm using a pulveriser. Table 1 represents the compositional and elemental properties of a cumbu napier grass to evaluate its suitability for biogas generation. The cumbu napier grass has a moisture content of 70.40 %, with a total solids content of 29.60 %. On a dry basis, it contains 79.70 % volatile matter, 7.50 % ash and 12.80 % fixed carbon. Its elemental composition includes 45.10 % carbon, 5.94 % hydrogen, 0.45 % nitrogen and no detectable sulphur. The cow dung has a moisture content of 81.2 % total solids content of 18.8 %. It consists of 74.30 % volatile matter, 14.10 % ash, 11.60 % fixed carbon. A high moisture content in cumbu napier grass will be well-suited for the biomethanation process as it facilitates microbial support, enables hydrolysis, dilutes inhibitors and enhances enzyme activity. The total solids content of 10 % is required for the biomethanation process, as Cumbu Napier grass possesses high total solids content; it can be diluted and used in the biomethanation process. A higher volatile content typically enhances the reactivity of the cumbu napier grass. The chemical composition of cumbu napier grass was cellulose 34.26 %, hemicellulose 23.44 % and lignin 22.32 %. Cellulose is a significant contributor and hemicellulose is more easily broken down than cellulose and can be a source for fermentable sugars for the biogas generation. Lignin is more resistant to decomposition; hence, it needs to be broken to enhance the biogas generation (42, 43).

Table 1. Characterisation of raw *Cumbu Napier* grass.

Properties	Value
Moisture content (% as received)	70.40 ± 2.11
Total solids content (% as received)	29.60 ± 2.10
Volatile content (% dry basis)	79.70 ± 6.30
Ash content (% dry basis)	7.50 ± 0.90
Fixed carbon (% dry basis)	12.80 ± 1.04
Carbon, (% dry basis)	45.10 ± 4.60
Hydrogen (% dry basis)	5.94 ± 0.65
Nitrogen (% dry basis)	0.45 ± 0.06
Sulphur (% dry basis)	0.00 ± 0.00
Oxygen (% dry basis)	48.52 ± 2.74
Cellulose (% dry basis)	34.26 ± 2.15
Hemicellulose (% dry basis)	23.44 ± 1.36
Lignin (% dry basis)	22.32 ± 1.10

Pretreatment of cumbu napier grass was carried out using a hydrothermal reactor at different pressures, 1 bar, 5 bar and 10 bar for effective destruction of lignin and to enhance the biogas yield. The process flow diagram is represented in Fig 1. The cellulose, hemicellulose and lignin content of pretreated cumbu napier grass are 35.6 %, 19.80 %, & 19.20 %; 40.21 %, 12.40 %, & 13.60 %; and 46.8 %, 8.70 %, & 10.30 % at 1 bar, 5 bar and 10 bar, respectively. SEM and FT-IR characterisation of raw and pretreated samples was carried out. Surface morphology of the raw and treated samples is studied by scanning electron microscope SEM images of the raw and treated samples are represented in Fig 2.

The SEM image of raw cumbu napier grass is used as a baseline for comparison. It was observed from the micrographs that the material underwent clear structural modifications as compared with the feedstock image. The external surface of the treated biomass was full of cavities, which resulted from the treatment of the biomass. The pores were visible in the magnified image in the micrographs of the treated sample. The hydrothermally pretreated sample at 1 bar, the process likely causes partial disruption of structural components, beginning the breakdown of lignocellulosic material. The hydrothermally pretreated sample at 5 bar results in more effective breakdown of the biomass structure, leading to greater disruption of hemicellulose and partial removal of lignin. Further, an increase in pressure to 10 bar results in higher disruption of hemicellulose and lignin to increase the viability of cellulose and overall bioconversion efficiency. It confirms post-treatment cavities, pore formation and fissures (especially at 5-10 bar) exhibit lignin/hemicellulose disruption vs. raw cumbu napier grass rigid matrix. Higher pressure in hydrothermal treatment alters the physical structure of biomass to enhance its suitability for bioenergy and bioproduct production (44)

FT-IR analysis of raw and pretreated cumbu napier grass is represented in Fig 3 to study the presence of components and their interaction. The FT-IR spectral peak indicates the functional group present in the samples. Major peaks, such as those around 3400 cm^{-1} , likely correspond to O-H stretching vibrations (from moisture or cellulose). Peaks around 2900 cm^{-1} might indicate C-H stretching vibrations from aliphatic groups in cellulose or hemicellulose. Other peaks between 1600-1000 cm^{-1} can be attributed to C-O stretching and C=C vibrations, commonly associated with lignocellulosic materials. Compared to the raw biomass, the intensity and position of the peaks may show slight changes due to the hydrothermal pretreatment at 1 bar. A reduction in O-H bond intensity (around 3400 cm^{-1}) indicates possible dehydration and removal of some moisture. The

structural changes caused by pretreatment likely lead to the partial breakdown of hemicellulose or lignin, reflected in shifts or intensity reductions in peaks around 1600-1000 cm^{-1} . At higher pressures (5 and 10 bar), more significant structural alterations occur in the biomass. The peak shifts and reductions at 3400 cm^{-1} (O-H bonds) and 2900 cm^{-1} (C-H stretching) suggest further breakdown of polysaccharides and release of water. Higher oxygen-containing compounds were obtained in the treated biomass compared to the raw biomass. The absorbance bands were observed to have peaks at 3200 to 3600 cm^{-1} (water molecules), 2850 to 3000 cm^{-1} (alkane), 1550 to 1640 cm^{-1} (amide), 1350 to 1480 cm^{-1} (alkane), 1210 to 1320 cm^{-1} (acid) and 1050 to 1150 cm^{-1} (alcohol) in cumbu napier grass samples. The peaks in the fingerprint region (below 1600 cm^{-1}) may show marked reductions, indicating lignin degradation and depolymerisation of complex carbohydrates. The trend in these spectra shows increasing structural decomposition of the sample with increasing pressure during hydrothermal pretreatment, as evident from changes in peak intensity and the positions of characteristic functional groups. This confirms the breakdown of lignocellulosic components such as cellulose, hemicellulose and lignin, enhancing the sample accessibility for further biomethanation process (45).

The biomethanation study is conducted with raw and treated samples and is represented in Fig 4. Table 2 presents the biogas yield, methane content and total solids (TS) destruction efficiency of cow dung co-digested with cumbu napier grass at different mixing ratios and under various hydrothermal pretreatment conditions (1 bar, 5 bar and 10 bar). The results highlight the impact of hydrothermal pretreatment and cow dung on the cumbu napier grass ratio on biogas production efficiency.

Hydrothermal pretreatment significantly improves the biogas yield, methane content and TS destruction efficiency of cow dung mixed with cumbu napier grass, with higher pressures generally producing better results. Raw cumbu napier grass and cow dung mixtures without pretreatment have lower yields and methane content, due to recalcitrance of lignin, indicating the requirement for pretreatment to enhance biomass digestibility. The pretreatment at 5 bar and 10 bar is particularly effective in improving the performance of mixed biomass samples, especially for the 3:1 and 1:1 ratios, where biogas yield and methane content are higher. The methane content variation in raw cumbu napier grass is as low as 6-23 % due to inhibition of hydrolysis by lignin, whereas pretreatment enhances methanogenesis to 42-58 %. The pretreated sample at 1 bar achieves 42-52 % due to moderate

Table 2. Biomethanation studies of raw and treated *Cumbu Napier* grass (RT: 60 days)

Sample	Cumbu Napier: Cow dung	Biogas yield (L/kg)	Methane content (%)	TS destruction efficiency (%)
Raw Cumbu Napier grass	1:0	0.30	6.35-8.50	8.20
	3:1	2.10	17.41-21.70	16.50
	1:1	1.21	10.96-15.30	12.90
	1:3	1.85	13.69-18.20	13.60
Hydrothermally pretreated Cumbu Napier grass at 1 bar	1:0	0.43	13.7-23.2	10.32
	3:1	1.98	43.5-49.5	14.20
	1:1	3.57	42.4-50.4	41.20
	1:3	6.20	43.0-52.0	47.30
Hydrothermally pretreated Cumbu Napier grass at 5 bar	1:0	3.48	19.3-36.8	28.70
	3:1	14.50	46.0-58.0	64.92
	1:1	5.70	46.3-57.2	44.60
	1:3	9.46	45.5-56.9	52.12
Hydrothermally pretreated Cumbu Napier grass at 10 bar	1:0	5.60	13.7-26.1	44.10
	3:1	10.02	47.3-55.9	52.70
	1:1	18.64	44.0-56.0	66.00
	1:3	10.35	44.3-54.4	53.40



Fig. 1. Process flow diagram of hydrothermal pretreatment of Cumbu Napier grass with cow dung for biogas production.

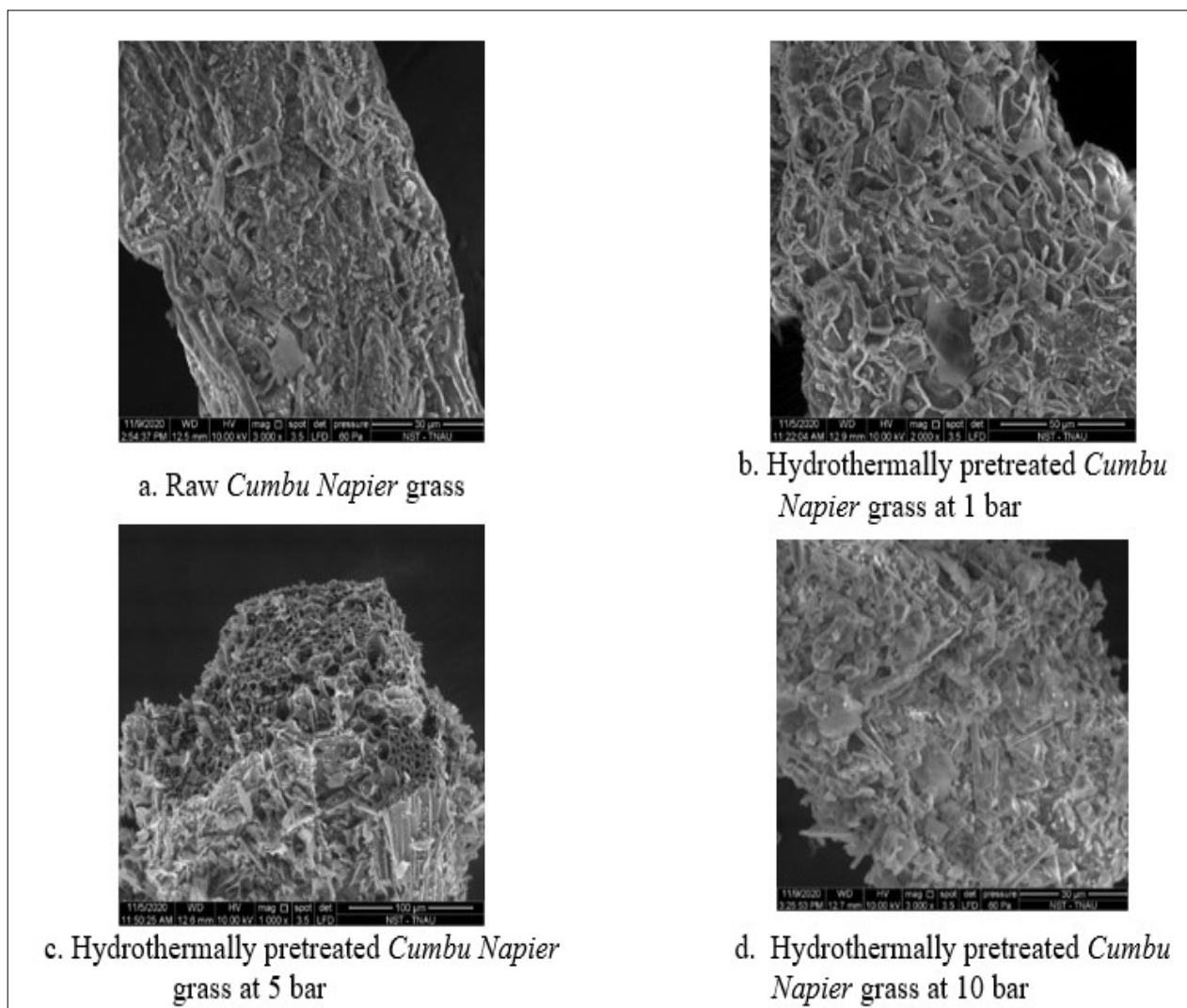


Fig. 2. SEM images of raw and treated Cumbu Napier grass.

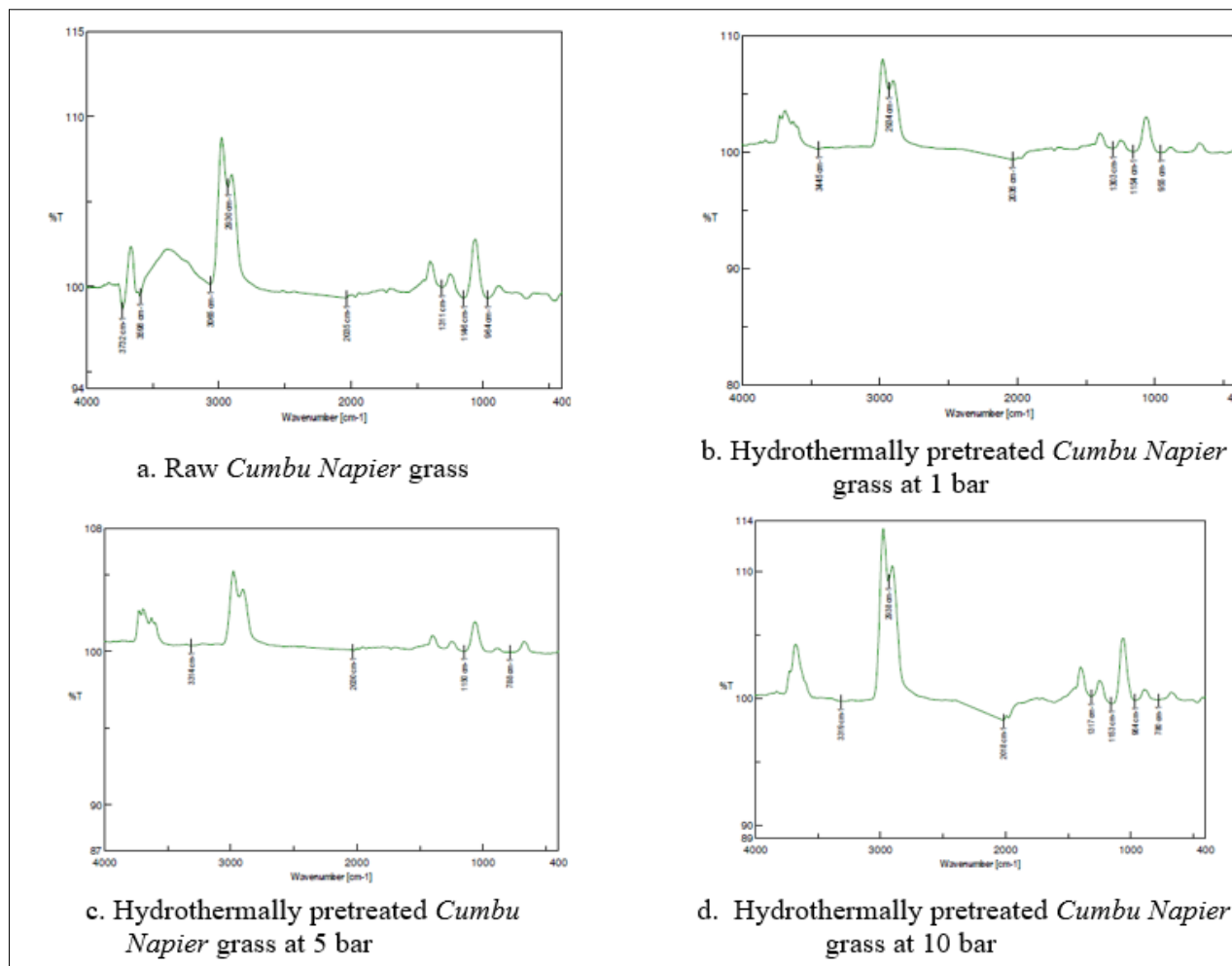


Fig. 3. FT-IR image of raw and treated biomass.



Fig. 4. Lab-scale biogas production study of hydrothermally pretreated Cumbu Napier grass.

hydrolysis; at 5 bar, peak methanogenesis is achieved by 46-58 % and 10 bar exhibits 44-56 % due to overload of acids. Among the various treatments on biogas production from treated cumbu napier grass, 3:1 ratio of cumbu napier grass and cow dung treated at 5 bar yields 14.50 L/kg of biogas with methane content ranging from 46.0-58.0 % and TS destruction efficiency of 64.92 % and 1:1 ratio of cumbu napier grass and cow dung treated at 10 bar yields highest biogas (18.64 L/kg) with methane content ranging from 44.0-56.0 % and a TS destruction efficiency of 66 %, indicating optimal degradation under this condition (46). The chemical constituents of raw and treated biomass and digested slurry, viz., lignin, hemicellulose and cellulose, are estimated before and after the digestion in all the treatments (47). The destruction efficiency is calculated to affirm the digestive process. The lignin, hemicellulose and cellulose destruction efficiency of treated cumbu napier grass are presented in Table 3. These metrics are crucial for evaluating how effectively the pretreatment process breaks down the structural components of the biomass, which improves its digestibility and facilitates biogas production.

From the table, raw cumbu napier grass (without pretreatment) shows relatively low destruction efficiencies across all chemical constituents, with lignin destruction being particularly limited. Hydrothermal pretreatment at 1 bar leads to noticeable improvements, especially in the 1:3 ratio, where cellulose destruction reaches 55.43 %. Hydrothermal pretreatment at 5 bar significantly increases the degradation of lignin, hemicellulose and cellulose. The 3:1 ratio achieves the highest efficiencies at this pressure, with over 67.44 % cellulose destruction. Pretreatment at 10 bar achieves the highest overall destruction efficiencies. The 1:1 ratio under these conditions shows the best performance, particularly with cellulose destruction reaching 79.64 %, making it the optimal condition for biomass breakdown. It also inferred that increasing hydrothermal pretreatment pressure and adjusting the cumbu napier-cow dung ratio enhances the breakdown of lignocellulosic biomass, optimising the efficiency of the biomethanation process (48).

The highest biogas yield at various treatment conditions of raw and pretreatment at different ratios is selected and its biodigestate is extracted for analysis in a GC-MS analyser. The GC-MS spectra reflect the various organic compounds that are present in the biodigested slurry as a result of the biomethanation process is depicted in Fig 5. The higher proportion of the components, viz.,

acetic acids, methyl ester, ethane, propanone, in lesser concentration indicates that higher digestion of the sample occurs and hydroxylamine, hydroxyurea, Urea, dimethylamine and ethyl acetate in higher concentration confirm the manure nutrient value. The spectrum for raw cumbu napier grass likely shows fewer breakdown products and may highlight more complex or heavier compounds that have not been fully broken down during the biodigestion process. As the hydrothermal pretreatment pressure increases (1 bar, 5 bar, 10 bar), the spectra of the samples are expected to show a shift towards simpler and lighter volatile compounds, indicating more complete degradation of the biomass. Higher pressure pretreatment at 5 bar and 10 bar would likely show peaks corresponding to simpler hydrocarbons, acids, alcohols, or other small molecules, indicating a higher degree of conversion and breakdown during biomethanation (49, 50).

The biodigestate value is validated with the macro-nutrient content in it (51). The organic carbon and nitrogen content of biodigestate to utilise as biofertilizer in agriculture, with a CN ratio value of (52). Table 4 represents the Carbon (%), Nitrogen (%) content and CN ratio of biodigestate. The nutrient value of biodigestate varied significantly between pretreated and raw cumbu napier grass. The macro-nutrient content of biodigestate, such as Carbon and nitrogen, is found out. The CN ratio of biodigestate is derived to find the suitability of biodigestate as a biofertilizer. The higher the pressure, the higher the breakdown of biochemical components of cumbu napier grass, with an increase in biogas yield and reduction in CN ratio in its biodigestate (53, 54). The biodigestate with the lowest CN ratio is achieved at a 1:1 ratio of cumbu napier grass treated at 10 bar and cow dung. This also validated the higher biogas yield at a 1:1 ratio of cumbu napier grass treated at 10 bar and cow dung with a CN ratio of 3.4. The CN ratio less than 5 is ideal for biofertilizer application and improved biodegradability (55, 56).

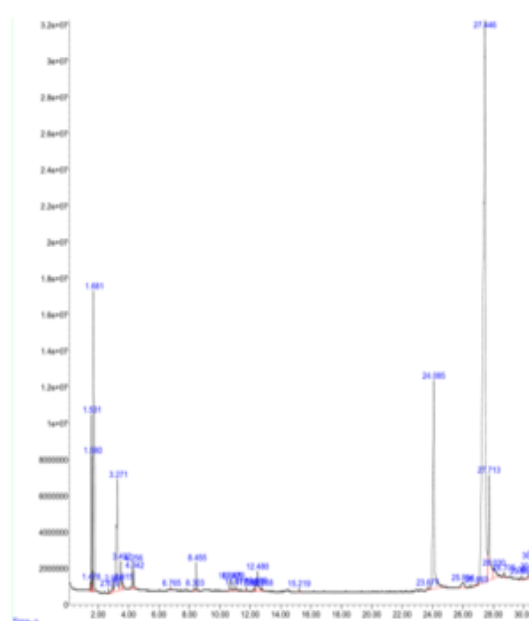
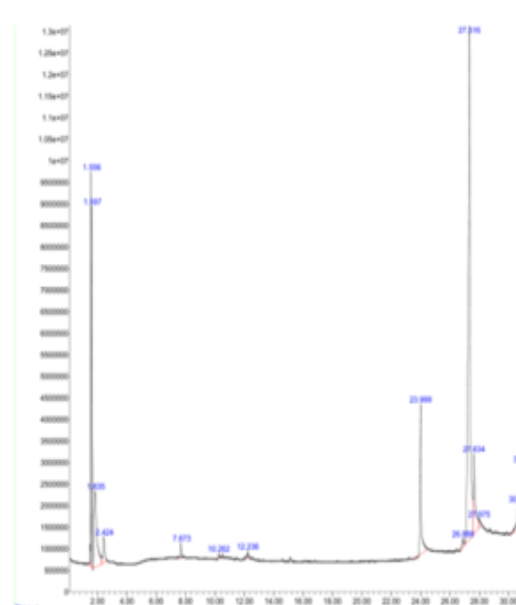
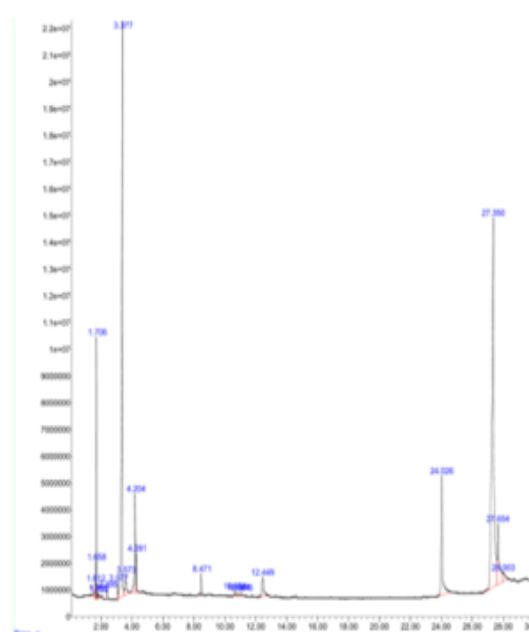
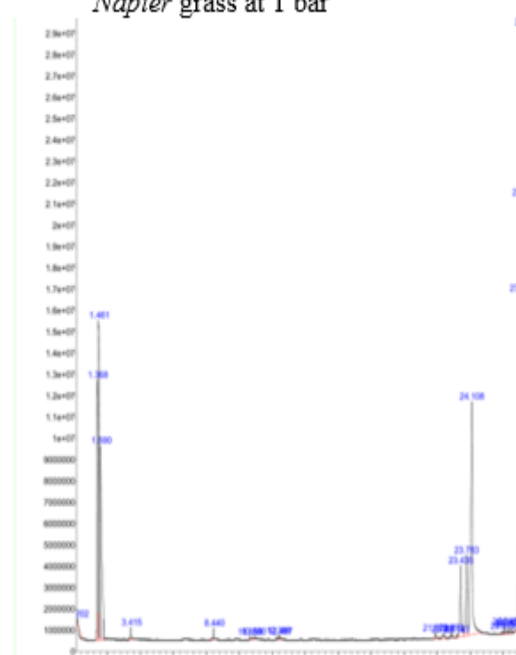
For a 1000 kg daily feeding using pretreated cumbu napier grass at 10 bar and cow dung in an equal ratio in an anaerobic digester. The capital cost of anaerobic digester, hydrothermal pretreatment reactor and other accessories is ₹15 lakh, ₹20 lakh and ₹5 lakh. The average operating cost will be approximately ₹3-4/kg feed material, including processing of cumbu napier grass, labour and energy consumption. If biogas sells at ₹40/m³, annual revenue is ₹13 lakh, with net profit of around 3 lakhs and a 3-4 year payback period without adding the benefit of digestate fertiliser value.

Table 3. Destruction efficiency of *Cumbu Napier* grass (raw and treated) through biomethanation in terms of chemical constituents

Sample	Cumbu Napier: Cow dung	Lignin destruction efficiency (%)	Hemi-cellulose destruction efficiency (%)	Cellulose destruction efficiency (%)
Raw Cumbu Napier grass	1:0	5.41	18.90	20.16
	3:1	14.32	37.48	44.06
	1:1	12.03	33.55	42.18
	1:3	12.31	36.35	42.30
Hydrothermally pretreated Cumbu Napier grass at 1 bar	1:0	10.12	20.92	34.52
	3:1	13.54	36.70	42.31
	1:1	18.63	46.32	51.20
	1:3	21.04	52.43	55.43
Hydrothermally pretreated Cumbu Napier grass at 5 bar	1:0	16.72	45.43	48.03
	3:1	43.42	64.08	67.44
	1:1	20.26	52.30	54.35
	1:3	31.17	54.38	56.90
Hydrothermally pretreated Cumbu Napier grass at 10 bar	1:0	20.12	50.38	53.77
	3:1	34.43	54.40	58.65
	1:1	56.40	67.20	79.64
	1:3	42.10	63.61	62.48

Table 4. Macro-nutrient content of biodigestate of Cumbu Napier grass

Sample	Cumbu Napier: Cow dung	Carbon (%)	Nitrogen (%)	CN ratio
Raw Cumbu Napier grass	1:0	21.15	0.9	23.5
	3:1	12.81	0.7	18.3
	1:1	11.6	0.8	14.5
	1:3	9.72	0.6	16.2
	1:0	16.16	0.8	20.2
Hydrothermally pretreated Cumbu Napier grass at 1 bar	3:1	7.38	0.6	12.3
	1:1	5.74	0.7	8.2
	1:3	7.55	0.5	15.1
	1:0	10.78	0.7	15.4
	3:1	1.64	0.4	4.1
Hydrothermally pretreated Cumbu Napier grass at 5 bar	1:1	10.32	0.6	17.2
	1:3	6.15	0.5	12.3
	1:0	5.80	0.7	8.3
	3:1	3.18	0.6	5.3
	1:1	1.36	0.4	3.4
Hydrothermally pretreated Cumbu Napier grass at 10 bar	1:3	3.95	0.5	7.9

**a.** Raw *Cumbu Napier* grass**b.** Hydrothermally pretreated *Cumbu Napier* grass at 1 bar**c.** Hydrothermally pretreated *Cumbu Napier* grass at 5 bar**d.** Hydrothermally pretreated *Cumbu Napier* grass at 10 bar**Fig. 5.** GC-MS spectra of a higher-yielding sample of bio-digested slurry.

Conclusion

This study discloses the influence of pretreatment of cumbu napier grass in enhancing the biogas yield and nutrient value of its biodigestate. The rise in pressure of hydrothermal pretreatment increased the degradation of biochemical composition of cumbu napier grass, leading to high biogas generation in terms of quality and quantity. The biomethanation of cumbu napier grass hydrothermally treated at 10 bar and cow dung in the ratio of 1:1 attained high total solids destruction and the highest biogas yield with rich biomanurial value biodigestate. The FT-IR and SEM analysis confirmed the structural modification in the sample, facilitating it for effective microbial digestion to higher biogas yield and biodegradability. The GCMS of biodigestate confirms that the simple volatile profiles lead to the effectiveness of biodigestion of pretreated biomass. This study confirms the suitability of hydrothermal pretreatment to enhance biogas yield and the potential of cumbu napier grass for biogas generation and the biomanurial value of biodigestate. Further research could explore scaling up this approach to an industrial level, assessing its techno-economic viability and environmental benefits.

Acknowledgements

The authors thank the ICAR-All India Coordinated Research Project on Energy in Agriculture and Agro-based Industries for funding this study. And also, we thank the Department of Renewable Energy Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, for providing assistance for conducting this research.

Authors' contributions

PV was involved in the analysis and writing of the original draft preparation. GJ was involved in the execution, data compilation and analysis. RPD was involved in data analysis and manuscript preparation. SS was involved in conceptualisation, methodology and supervision. DR was involved in review, editing and Supervision. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Abu-Dahrieh J, Orozco A, Groom E, Rooney D. Batch and continuous biogas production from grass silage liquor. *Bioresour Technol.* 2011;102(23):10922–8. <https://doi.org/10.1016/j.biortech.2011.09.072>
2. Akhtar N, Gupta K, Goyal D, Goyal A. Recent advances in pretreatment technologies for efficient hydrolysis of lignocellulosic biomass. *Environ Prog Sustain Energy.* 2016;35(2):489–511. <https://doi.org/10.1002/ep.12257>
3. Gitanjali J, Pugalendhi S, Kamaraj S, Karthikeyan S, Kumar VJF. Feasibility test of agricultural residues through characterization for utilization in plasma gasification. *Indian J Agric Sci.* 2015;85(12):1534–9. <https://doi.org/10.56093/ijas.v85i12.54290>
4. Anex RP, Lynd LR, Laser MS, Heggenstaller AH, Liebman M. Potential for enhanced nutrient cycling through coupling of agricultural and bioenergy systems. *Crop Sci.* 2007;47(4):1327–35. <https://doi.org/10.2135/cropsci2006.06.0406>
5. Antonopoulou G, Vayenas D, Lyberatos G. Biogas production from physicochemically pretreated grass lawn waste: Comparison of different process schemes. *Molecules.* 2020;25(2):296. <https://doi.org/10.3390/molecules25020296>
6. Beausang C, McDonnell K, Murphy F. Assessing the environmental sustainability of grass silage and cattle slurry for biogas production. *J Clean Prod.* 2021;298:126838. <https://doi.org/10.1016/j.jclepro.2021.126838>
7. Bedoić R, Čuček L, Čosić B, Krajnc D, Smoljanić G, Kravanja Z, et al. Green biomass to biogas—A study on anaerobic digestion of residue grass. *J Clean Prod.* 2019;213:700–9. <https://doi.org/10.1016/j.jclepro.2018.12.224>
8. Bharathiraja B, Sudharsana T, Jayamuthunagai J, Praveenkumar R, Chozhavendhan S, Iyyappan J. Biogas production—A review on composition, fuel properties, feed stock and principles of anaerobic digestion. *Renew Sustain Energy Rev.* 2018;90:570–82. <https://doi.org/10.1016/j.rser.2018.03.093>
9. Blokhina YN, Prochnow A, Plöchl M, Luckhaus C, Heiermann M. Concepts and profitability of biogas production from landscape management grass. *Bioresour Technol.* 2011;102(2):2086–92. <https://doi.org/10.1016/j.biortech.2010.08.002>
10. Choi Y, Ryu J, Lee SR. Influence of carbon type and carbon to nitrogen ratio on the biochemical methane potential, pH and ammonia nitrogen in anaerobic digestion. *J Anim Sci Technol.* 2020;62(1):74. <https://doi.org/10.5187/jast.2020.62.1.74>
11. Dalpaz R, Konrad O, da Silva Cyrne CC, Barzotto HP, Hasan C, Guerini Filho M. Using biogas for energy cogeneration: An analysis of electric and thermal energy generation from agro-industrial waste. *Sustain Energy Technol Assess.* 2020;40:100774. <https://doi.org/10.1016/j.seta.2020.100774>
12. Dar RA, Parmar M, Dar EA, Sani RK, Phutela UG. Bio-methanation of agricultural residues: Potential, limitations and possible solutions. *Renew Sustain Energy Rev.* 2021;135:110217. <https://doi.org/10.1016/j.rser.2020.110217>
13. Das A, Mondal C, Roy S. Pretreatment methods of ligno-cellulosic biomass: A review. *J Eng Sci Technol Rev.* 2015;8(5):20. <https://doi.org/10.25103/jestr.085.20>
14. Fazal MA, Rubaiee S, Al-Zahrani A. Overview of the interactions between automotive materials and biodiesel obtained from different feedstocks. *Fuel Process Technol.* 2019;196:106178. <https://doi.org/10.1016/j.fuproc.2019.106178>
15. Ferdeş M, Zăbavă BŞ, Paraschiv G, Ionescu M, Dincă MN, Moiceanu G. Food waste management for biogas production in the context of sustainable development. *Energies.* 2022;15(17):6268. <https://doi.org/10.3390/en15176268>
16. Ferrer A, Alciaturi C, Faneite A, Ríos J. Analyses of biomass fibers by XRD, FT-IR and NIR. In: Vaz J S, editor. *Analytical techniques and methods for biomass.* 2016. p.45–83. https://doi.org/10.1007/978-3-319-41414-0_3
17. Hu F, Ragauskas A. Pretreatment and lignocellulosic chemistry. *BioEnergy Res.* 2012;1043–66. <https://doi.org/10.1007/s12155-012-9208-0>
18. Idrees M, Adnan A, Qureshi FA. Comparison of acid and alkali catalytic efficiency during enzymatic saccharification of corncob and lactic acid production. *Pak J Agric Sci.* 2014;51(4).
19. Ioelovich M. Methods for determination of chemical composition of plant biomass. *J SITA.* 2015;17(4):208–14.
20. Jomnonkhaow U, Sittijunda S, Reungsang A. Influences of size reduction, hydration and thermal-assisted hydration pretreatment to increase the biogas production from Napier grass and Napier silage. *Bioresour Technol.* 2021;331:125034. <https://doi.org/10.1016/j.biortech.2021.125034>

21. Kainthola J, Kalamdhad AS, Goud VV. A review on enhanced biogas production from anaerobic digestion of lignocellulosic biomass by different enhancement techniques. *Process Biochem.* 2019;84:81–90. <https://doi.org/10.1016/j.procbio.2019.05.023>
22. Kalinichenko A, Havrysh V, Perebyynis V. Evaluation of biogas production and usage potential. *Ecol Chem Eng S.* 2016;23(3):387–400. <https://doi.org/10.1515/eces-2016-0027>
23. Kammoun M, Margellou A, Toteva VB, Aladjadjiyan A, Sousa AF, Luis SV, et al. The key role of pretreatment for the one-step and multi-step conversions of European lignocellulosic materials into furan compounds. *RSC Adv.* 2023;13(31):21395–420. <https://doi.org/10.1039/D3RA01533E>
24. Kasulla S, Malik SJ, Yadav A, Kathpal G. Potential of biogas generation from hybrid Napier grass. *Int J Trend Sci Res Dev.* 2022;6(2): 277–81.
25. Khan IU, Othman MH, Hashim H, Matsuura T, Ismail AF, Rezaei-DashtArzhandi M, et al. Biogas as a renewable energy fuel–A review of biogas upgrading, utilisation and storage. *Energy Convers Manag.* 2017;150:277–94. <https://doi.org/10.1016/j.enconman.2017.08.035>
26. Pugalendhi S, Gitanjali J, Shalini R, Subramanian P. Handbook on renewable energy and green technology. CRC Press; 2024. p.20. <https://doi.org/10.1201/9781032711911>
27. Kumar V, Yadav SK, Kumar J, Ahluwalia V. A critical review on current strategies and trends employed for removal of inhibitors and toxic materials generated during biomass pretreatment. *Bioresour Technol.* 2020;299:122633. <https://doi.org/10.1016/j.biortech.2019.122633>
28. Manfredini A, Chiariotti A, Santangelo E, Rossi E, Renzi G, Dell'Abate MT. Assessing the biological value of soluble organic fractions from tomato pomace digestates. *J Soil Sci Plant Nutr.* 2021;21(1):301–14. <https://doi.org/10.1007/s42729-020-00361-4>
29. Manyi-Loh CE, Lues R. Anaerobic digestion of lignocellulosic biomass: Substrate characteristics (challenge) and innovation. *Fermentation.* 2023;9(8):755. <https://doi.org/10.3390/fermentation9080755>
30. Mirmohamadsadeghi S, Karimi K, Azarbaijani R, Yeganeh LP, Angelidaki I, Nizami AS, et al. Pretreatment of lignocelluloses for enhanced biogas production: A review on influencing mechanisms and the importance of microbial diversity. *Renew Sustain Energy Rev.* 2021;135:110173. <https://doi.org/10.1016/j.rser.2020.110173>
31. Mukherjee A, Patra BR, Pattnaik F, Okolie JA, Sonil N, Dalai AK. Biomethane production through anaerobic digestion of lignocellulosic biomass and organic wastes. In: Nanda S, Sarangi PK, editors. *Biomethane*. Boca Raton: CRC Press; 2022. p. 61–92. <https://doi.org/10.1201/9781003277163-4>
32. Mussatto SI, Fernandes M, Milagres AM, Roberto IC. Effect of hemicellulose and lignin on enzymatic hydrolysis of cellulose from brewers' spent grain. *Enzyme Microb Technol.* 2008;43(2):124–9. <https://doi.org/10.1016/j.enzmictec.2007.11.006>
33. Narendra N, Ramakrishnan V, Thomas A, Lambodhar UA, Suhas K. Characterization and feasibility of biogas yield using mango fruit peels and durva grass. *Mater Today Proc.* 2021;47:4624–9. <https://doi.org/10.1016/j.matpr.2021.05.479>
34. Paritosh K, Yadav M, Kesharwani N, Pareek N, Karthikeyan OP, Balan V, et al. Strategies to improve solid state anaerobic bioconversion of lignocellulosic biomass: An overview. *Bioresour Technol.* 2021;331:125036. <https://doi.org/10.1016/j.biortech.2021.125036>
35. Pinpatthanapong K, Boonnorat J, Glanpracha N, Rangseesuriyachai T. Biogas production by co-digestion of sodium hydroxide pretreated Napier grass and food waste for community sustainability. *Energy Sources A.* 2022;44(1):1678–92. <https://doi.org/10.1080/15567036.2022.2055232>
36. Poddar BJ, Nakhate SP, Gupta RK, Chavan AR, Singh AK, Khardenavis AA, et al. A comprehensive review on the pretreatment of lignocellulosic wastes for improved biogas production by anaerobic digestion. *Int J Environ Sci Technol.* 2022;1–28.
37. Prasad RK, Sharma A, Mazumder PB, Dhussa A. A comprehensive pre-treatment strategy evaluation of ligno-hemicellulosic biomass to enhance biogas potential in the anaerobic digestion process. *RSC Sustain.* 2024;2(9):2444–67. <https://doi.org/10.1039/D4SU00099D>
38. Qian P, Schoenau JJ. Availability of nitrogen in solid manure amendments with different C:N ratios. *Can J Soil Sci.* 2002;82(2):219–25. <https://doi.org/10.4141/S01-018>
39. Rabi Prasad B, Polaki S, Padhi RK, Manoja D. Comprehensive characterization of lignocellulosic biomass and their effective delignification for sustainable bioenergy. *Res J Chem Environ.* 2024;28:1. <https://doi.org/10.25303/281rjce57067>
40. Ramos A, Monteiro E, Rouboa A. Biomass pre-treatment techniques for the production of biofuels using thermal conversion methods–A review. *Energy Convers Manag.* 2022;270:116271. <https://doi.org/10.1016/j.enconman.2022.116271>
41. Rangseesuriyachai T, Boonnorat J, Glanpracha N, Khetkorn W, Thiamngoen P, Pinpatthanapong K. Anaerobic co-digestion of elephant dung and biological pretreated Napier grass: Synergistic effect and kinetics of methane production. *Biomass Bioenergy.* 2023;175:106849. <https://doi.org/10.1016/j.biombioe.2023.106849>
42. Rodríguez C, Alaswad A, Benyounis KY, Olabi AG. Pretreatment techniques used in biogas production from grass. *Renew Sustain Energy Rev.* 2017;68:1193–204. <https://doi.org/10.1016/j.rser.2016.02.022>
43. Sahay S. Impact of pretreatment technologies for biomass to biofuel production. In: *Substrate analysis for effective biofuels production*. 2020. p.173–216. https://doi.org/10.1007/978-981-32-9607-7_7
44. Sawasdee V, Pisutpaisal N. Feasibility of biogas production from Napier grass. *Energy Procedia.* 2014;61:1229–33. <https://doi.org/10.1016/j.egypro.2014.11.1064>
45. Scherzinger M, Kaltschmitt M. Thermal pre-treatment options to enhance anaerobic digestibility–A review. *Renew Sustain Energy Rev.* 2021;137:110627. <https://doi.org/10.1016/j.rser.2020.110627>
46. Singh RP, Gautam M, Vaish B, Agrahari RK, Singh P, Singh RP. Explicating the fertilizing potential of anaerobic digestate on soil quality, growth and yield responses of *Solanum lycopersicum* var. Kashi Aman. *Int J Environ Res.* 2025;19(1):65. <https://doi.org/10.1007/s41742-024-00733-z>
47. Tsapekos P, Kougias PG, Angelidaki I. Biogas production from ensiled meadow grass; effect of mechanical pretreatments and rapid determination of substrate biodegradability via physicochemical methods. *Bioresour Technol.* 2015;182:329–35. <https://doi.org/10.1016/j.biortech.2015.02.025>
48. Wang J, Ma D, Lou Y, Ma J, Xing D. Optimization of biogas production from straw wastes by different pretreatments: Progress, challenges and prospects. *Sci Total Environ.* 2023;166992. <https://doi.org/10.1016/j.scitotenv.2023.166992>
49. Warade H, Nagarnaik PB, Daryapurkar R. Feasibility of biogas production from napier grass using animal manure as co-substrate on pilot scale reactor. *Water Energy Int.* 2019;62(3):36–41.
50. Woiciechowski AL, Neto CJ, de Souza Vandenbergh LP, de Carvalho Neto DP, Sydney AC, Letti LA, et al. Lignocellulosic biomass: Acid and alkaline pretreatments and their effects on biomass recalcitrance–Conventional processing and recent advances. *Bioresour Technol.* 2020;304:122848. <https://doi.org/10.1016/j.biortech.2020.122848>
51. Xu JK, Sun RC. Recent advances in alkaline pretreatment of lignocellulosic biomass. In: *Biomass fractionation technologies for a lignocellulosic feedstock based biorefinery*. 2016. p.431–59. <https://doi.org/10.1016/B978-0-12-802323-5.00019-0>
52. Yang K, Zhang Z, Liu Y, Li S, Chen D, Li Z. Biomass-based porous composites with heat transfer characteristics: Preparation, performance and evaluation–A review. *J Porous Mater.* 2022;29(6):1667–87. <https://doi.org/10.1007/s10934-022-01296-0>
53. You T, Xu F. Applications of molecular spectroscopic methods to the

- elucidation of lignin structure. In: Stauffer MT, editor. Applications of molecular spectroscopy to current research in the chemical and biological sciences [Internet]. London: IntechOpen; 2016 [cited 2026 Mar 14]. p. 161–191. Available from: <https://www.intechopen.com/chapters/51761> <https://doi.org/10.5772/64581>
54. Zeshan KO, Visvanathan C. Effect of C/N ratio and ammonia-N accumulation in a pilot-scale thermophilic dry anaerobic digester. *Bioresour Technol.* 2012;113:294–302. <https://doi.org/10.1016/j.biortech.2012.02.028>
 55. Zheng Y, Zhao J, Xu F, Li Y. Pretreatment of lignocellulosic biomass for enhanced biogas production. *Prog Energy Combust Sci.* 2014;42:35–53. <https://doi.org/10.1016/j.pecs.2014.01.001>
 56. Souvannasouk V, Shen MY, Trejo M, Bhuyar P. Biogas production from Napier grass and cattle slurry using a green energy technology. *Int J Innov Res Sci Stud.* 2021;4(3):174–80. <https://doi.org/10.53894/ijirss.v4i3.74>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc. See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.