Enhancement of biogas production from vegetable leftovers using carbon additives

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***Abstract*—India being a major global producer of fruits and vegetables could also result in significant waste generation and loss to spoilage and unscientific handling of raw materials. These otherwise discarded material can be subjected to bio-methanation for the production biogas which can be used as sustainable source of fuel. However, the type of raw material used for bio-methanation could determine the efficiency of the process. For instance, employing waste from slaughter house and fish markets could result in alkaline drift and ultimately process failure in anaerobic digesters owing to generation of excess ammonia from the raw material. From this study, a net improvement in biogas production using vegetable leftovers as feedstock were observed upon addition of carbon additives like coconut shell charcoal, bagasse charcoal, saw dust charcoal as well as rice husk charcoal on comparison with control. Maximum biogas production was observed in test samples added with bagasse charcoal powder. Biogas production from vegetable waste containing cabbage leftovers supplemented with prawn peel powder showed a substantial increase. Process failure due to addition of poultry and fish waste could be ameliorated upon addition of coconut shell charcoal and bagasse powder charcoal. Addition of the charcoal powder from coconut shells could relieve process failure and repression caused by limonene with maximum relief with mosambi peels.**

***Index Terms*—Anaerobic digestion, bagasse powder charcoal, biogas, coconut shell charcoal, cost efficiency, mosambi peels, prawn peel powder, rice husk charcoal, renewable energy, saw dust charcoal, vegetable leftovers.**

I. INTRODUCTION

Energy is the basic input required to sustain economic growth and to provide basic amenities of life to the entire population of a country. Energy can be an effective weapon in the battle against abject poverty, in a country like India. Like other developing countries, India is also in the process of planning and development of such a quantum of energy for its developmental plans. It is the level and pattern of utilization of energy from different sources in any country, which is an index of industrial development and standard of living. Basically, energy is utilized in three key sectors of our economy and namely agriculture, industry and households. We use energy produced from the most elementary agricultural wastes as well as from highly sophisticated nuclear fuel. Renewable energy production from animal and agro-industrial wastes should be adopted to compensate for fossil fuel consumption in order to reduce greenhouse gas emission and consequently to prevent global warming. Anaerobic digestion is considered to be one of the most economical ways of producing bioenergy from biomass and has been used very effectively to treat various household, industrial and agricultural organic wastes. At the same time, it will also solve the problem of methane leakage from different industrial and household wastes. The need for renewable sources of energy in developing countries like India is critical for several reasons. Firstly, these countries often face energy deficits and rely heavily on fossil fuels, which are not only finite but also contribute significantly to environmental degradation and climate change. Secondly, developing countries like India have a rapidly growing population and increasing energy demands. Bio fuels have emerged as a crucial solution to address the pressing need for sustainable energy sources by greatly helping reduce dependence on finite fossil fuels, which are subject to price volatility and geopolitical tensions, which could ultimately help reduce air pollution and improving air quality. Biofuels can be categorized into different generations based on their feedstock and production methods. First-generation biofuels are derived from food crops grown on arable land, where the sugar, starch, or oil content is converted into biodiesel or ethanol through transesterification or yeast fermentation. Second-generation biofuels, on the other hand, are made from lignocellulosic biomass or agricultural residues/waste. Each generation has its own advantages and challenges, and ongoing research and innovation are needed to optimize their production and overcome limitations. Vegetable waste is primarily composed of organic matter, including cellulose, hemicellulose, lignin, and various nutrients. It also contains water, some proteins, lipids, minerals, and vitamins. Vegetable waste typically has a high moisture content, which can range from 70% to 90% depending on the freshness and type of vegetable. High moisture content can contribute to the rapid degradation and decomposition of vegetable waste. Due to its high organic content, vegetable waste is biodegradable and decomposes relatively quickly under suitable conditions. The decomposition rate can be influenced by factors such as temperature, moisture, oxygen availability, and the presence of microorganisms. Biogas, a renewable source of energy, is produced from organic waste materials such as agricultural residues, food waste, and animal manure. This versatile energy source offers numerous benefits across various sectors. Biogas helps reduce reliance on fossil fuels and contributes to a sustainable energy mix, supporting the transition to a greener future. Biogas projects also contribute to job creation, offering employment opportunities in various stages, including design, construction, operation, and maintenance of biogas plants. This not only supports local economic development but also provides sustainable livelihoods for communities. The applications of biogas are diverse and include electricity generation, heating, cooking, and even transportation fuel. Biogas is a valuable renewable energy source that offers a wide range of benefits. From reducing reliance on fossil fuels to mitigating greenhouse gas emissions, improving waste management, promoting energy independence, and supporting agriculture, biogas plays a crucial role in sustainable development and offers a promising solution for a greener and more sustainable future.

II. MATERIALS AND METHODS

Materials:

Fresh cow dung, rotten vegetable wastes, tap water, measuring cylinder, 1000 mL conical flasks, rubber stopper with one and two holes, rubber tube, wooden stand for gas collection, plastic beaker, glass bottle, grinder, coconut shell charcoal, bagasse powder charcoal, saw dust charcoal, rice husk charcoal, prawn peel powder, boiled poultry waste, boiled fish waste, lemon peel waste, orange peel waste, mosambi peel waste, sodium alginate powder, calcium chloride solution.

Method:

Cow dung slurry was prepared by mixing 100g fresh cow dung with 100mL tap water, the slurry was made up to 700mL with tap water and poured into a 1000 mL conical flask. This sample was used as negative control throughout the study. The conical flask was closed with single holed rubber stopper connected with tubing to an inverted conical flask filled with water and closed with double holed rubber stopper. The outlet tubing of the inverted conical flask was placed in a glass bottle containing 100mL of water. Fermentation gases produced were collected in the bottle by water displacement method and daily displaced volume was measured using a measuring cylinder which was equal to the daily biogas produced from the particular set up. This set up was used throughout the study to assess the cumulative biogas production over a period of 5 days.

A. Bio-methanation using vegetable waste as feedstock

100g fresh cow dung was mixed with 100g finely ground brinjal waste (test I), finely ground cauliflower waste (test II), 100g finely ground cabbage waste (test III), 100g ash gourd waste (test IV), 100g tomato waste (test V) and the final volume was made up to 700mL, poured into a 1000mL conical flask and biogas production analyzed using water displacement as specified above.

B. Bio-methanation of vegetable wastes with coconut shell charcoal as carbon source

Slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III), ash gourd waste (test IV) and tomato waste (test V) separately. Each slurry was mixed with 1.5%(w/v) coconut shell charcoal and the total amount was made up to 700mL and poured into a 1000mL conical flask to check for biogas production as in above section.

C. Bio-methanation of vegetable waste with bagasse powder charcoal as carbon source

Test samples were prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III), ash gourd waste (test IV) and tomato waste (test V) separately. Each slurry was mixed with 1.5%(w/v) bagasse charcoal powder and the total amount was made up to 700mL and poured into a 1000mL conical flask to check for biogas production as in above section.

D. Bio-methanation of vegetable wastes with sawdust charcoal as carbon source

Test samples were prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III), ash gourd waste (test IV) and tomato waste (test V) separately. Each slurry was mixed with 1.5%(w/v) sawdust charcoal powder and the total amount was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

E. Bio-methanation of vegetable wastes with rice husk charcoal as carbon source

Slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III), ash gourd waste (test IV) and tomato waste (test V) separately. Each slurry was mixed with 1.5%(w/v) rice husk charcoal and the total amount was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

F. Bio-methanation of rotten vegetable wastes with prawn peel supplementation in the presence of coconut shell charcoal

To prepare prawn peel powder, 500g of prawns were purchased from local market and peeled to remove head portion. The peels were then dried in sunlight for one week. Dried prawn peel was ground to powder using a grinder. The slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III) separately. Each slurry was mixed with 1.5%(w/v) coconut shell charcoal, 5%(w/v) prawn peel powder, mixed well and the total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

G. Bio-methanation of rotten vegetable wastes with prawn peel supplementation in the presence of bagasse powder charcoal

Slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III) separately. Each slurry was mixed with 1.5%(w/v) bagasse powder charcoal, 5%(w/v) prawn peel powder, mixed well and the total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

H. Bio-methanation of rotten vegetable wastes with prawn peel supplementation in the presence of rice husk charcoal

Slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III) separately. Each slurry was mixed with 1.5%(w/v) rice husk charcoal, 5%(w/v) prawn peel powder, mixed well and the total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

I. Bio-methanation of rotten vegetable wastes with prawn peel supplementation in the presence of sawdust charcoal

Slurry was prepared by mixing 100g of fresh cow dung with 100g each of brinjal waste (test I), cauliflower waste (test II), cabbage waste (test III) separately. Each slurry was mixed with 1.5%(w/v) sawdust charcoal, 5%(w/v) prawn peel powder, mixed well and the total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

J. Bio-methanation of poultry waste with coconut shell charcoal as additive

Slurry was prepared by mixing 100g of fresh cow dung with 100g of boiled chicken waste, 10%(w/v) coconut shell charcoal (test I) and another set containing 10%(w/v) bagasse powder charcoal (test II). The total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

K. Bio-methanation of fish waste with coconut shell charcoal as additive

Slurry was prepared by mixing 100g of fresh cow dung with 100g of boiled fish waste, 10%(w/v) coconut shell charcoal (test I) and another set containing 10%(w/v) bagasse powder charcoal (test II). The total volume was made up to 700mL and poured into a 1000mL conical flask to check for biogas production.

L. Bio-methanation of lemon peel with coconut shell charcoal as additive

Slurry was made by mixing 100g fresh cow dung with 100g lemon peel waste. To the slurry 10%(w/v) coconut shell charcoal was mixed and the final volume made up into 700mL, and then poured into a 1000mL conical flask. Then the fermentation flask was connected with an inverted conical flask filled with water. The daily displaced water was collected and measured.

M. Bio-methanation of orange peel with coconut shell charcoal as additive

Slurry was made by mixing 100g fresh cow dung with 100g orange peel waste. To the slurry 10%(w/v) coconut shell charcoal was mixed and the final volume made up into 700mL, and then poured into a 1000mL conical flask. Then the fermentation flask was connected with an inverted conical flask filled with water. The daily displaced water was collected and measured.

N. Bio-methanation of mosambi peel with coconut shell charcoal as additive

Slurry was made by mixing 100g fresh cow dung with 100g mosambi peel waste. To the slurry 10%(w/v) coconut shell charcoal was mixed and the final volume made up into 700mL, and then poured into a 1000mL conical flask. Then the fermentation flask was connected with an inverted conical flask filled with water. The daily displaced water was collected and measured.

O. Bio-methanation of fruit juice with immobilized anaerobic bacteria

To prepare calcium alginate beads,100 mL 5% (w/v) solution of calcium alginate. Using a dropper droplets of sodium alginate solution were release into 2M calcium chloride solution, the droplets formed beads as they came into contact with calcium chloride. Allowed the beads to stay in the calcium chloride bath for a few minutes, and then washed the beads in normal water. Test samples were prepared by adding add ten calcium alginate beads each to 20mL grape juice (test I) and 20mL pineapple juice (test II) taken in boiling tubes, and were kept undisturbed for 24h and observed for gas production.

III. RESULTS

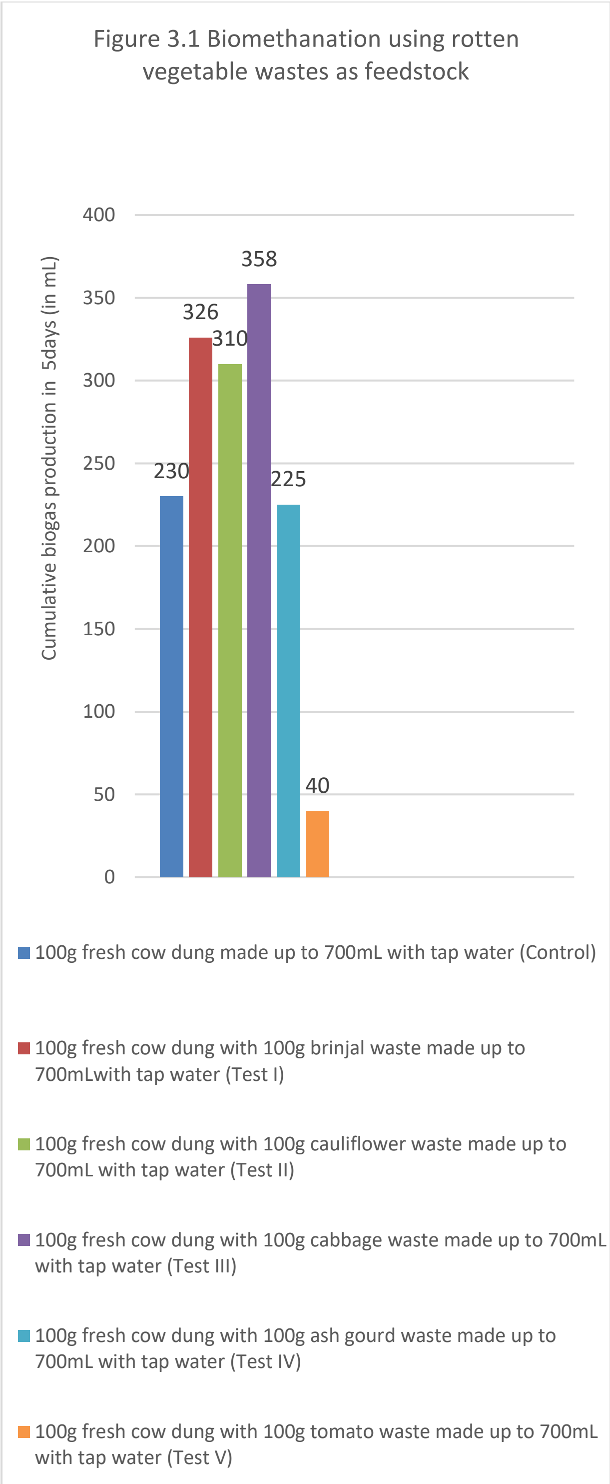


Figure 3.1 Biomethanation using rotten vegetable wastes as feedstock
Cumulative biogas production in 5days (in mL)
400
350
300
250
200
150
100
50
0
230
326
310
358
225
40
100g fresh cow dung made up to 700mL with tap water (Control)
100g fresh cow dung with 100g brinjal waste made up to 700mLwith tap water (Test I)
100g fresh cow dung with 100g cauliflower waste made up to 700mL with tap water (Test II)
100g fresh cow dung with 100g cabbage waste made up to 700mL with tap water (Test III)
100g fresh cow dung with 100g ash gourd waste made up to 700mL with tap water (Test IV)
100g fresh cow dung with 100g tomato waste made up to 700mL with tap water (Test V)

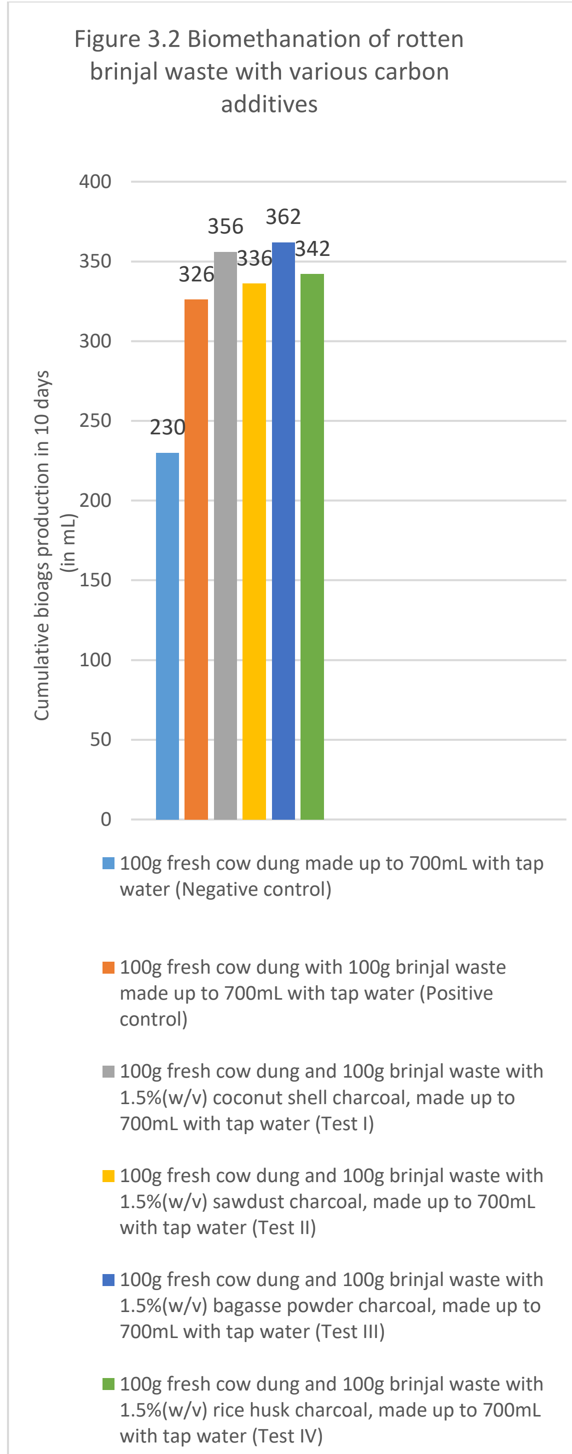


Figure 3.2 Biomethanation of rotten brinjal waste with various carbon additives
Cumulative bioags production in 10 days (in mL)
400
350
300
250
200
150
100
50
0
230
326
356
336
362
342
100g fresh cow dung made up to 700mL with tap water (Negative control)
100g fresh cow dung with 100g brinjal waste made up to 700mL with tap water (Positive control)
100g fresh cow dung and 100g brinjal waste with 1.5%(w/v) coconut shell charcoal, made up to 700mL with tap water (Test I)
100g fresh cow dung and 100g brinjal waste with 1.5%(w/v) sawdust charcoal, made up to 700mL with tap water (Test II)
100g fresh cow dung and 100g brinjal waste with 1.5%(w/v) bagasse powder charcoal, made up to 700mL with tap water (Test III)
100g fresh cow dung and 100g brinjal waste with 1.5%(w/v) rice husk charcoal, made up to 700mL with tap water (Test IV)

Figure 3.3. Biomethanation of rotten cauliflower waste with various carbon additives

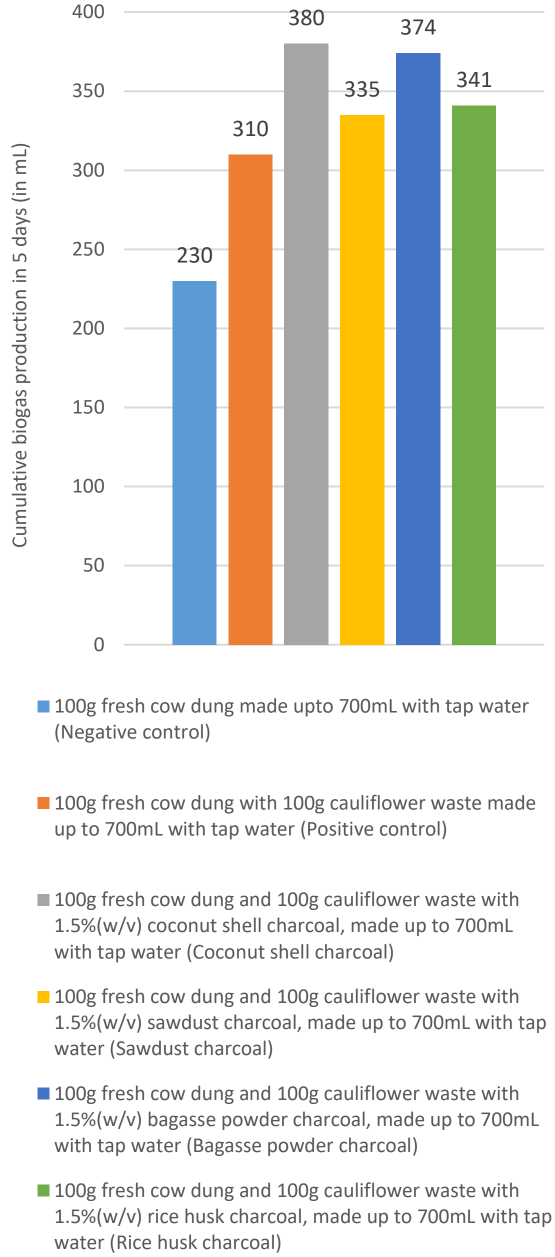


Figure 3.4. Biomethanation of rotten cabbage waste with various carbon additives

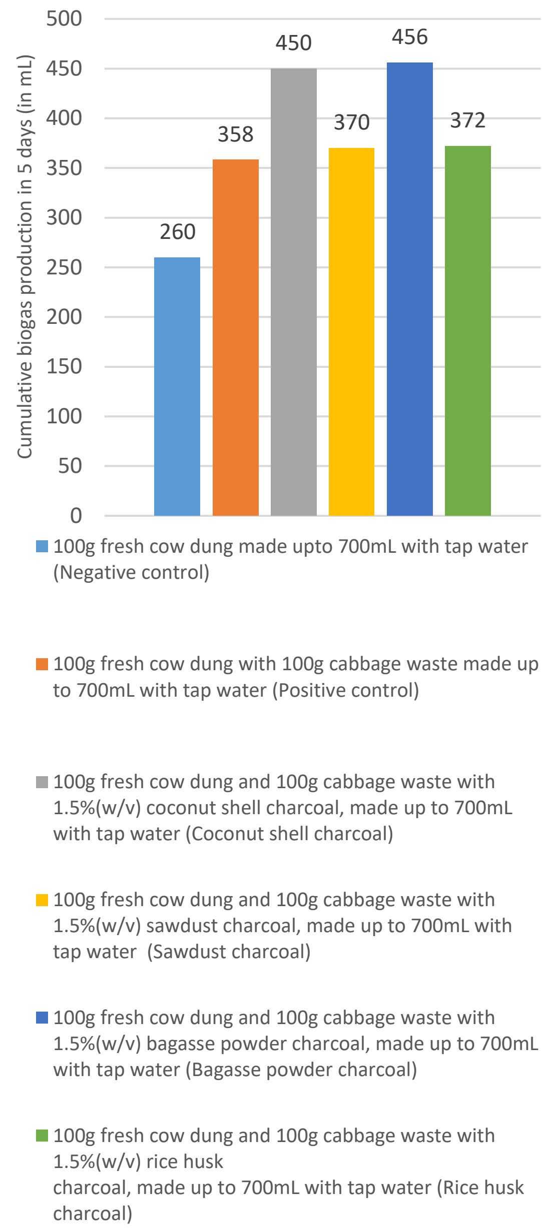


Figure 3.5. Biomethanation of rotten ash gourd waste with various carbon additives

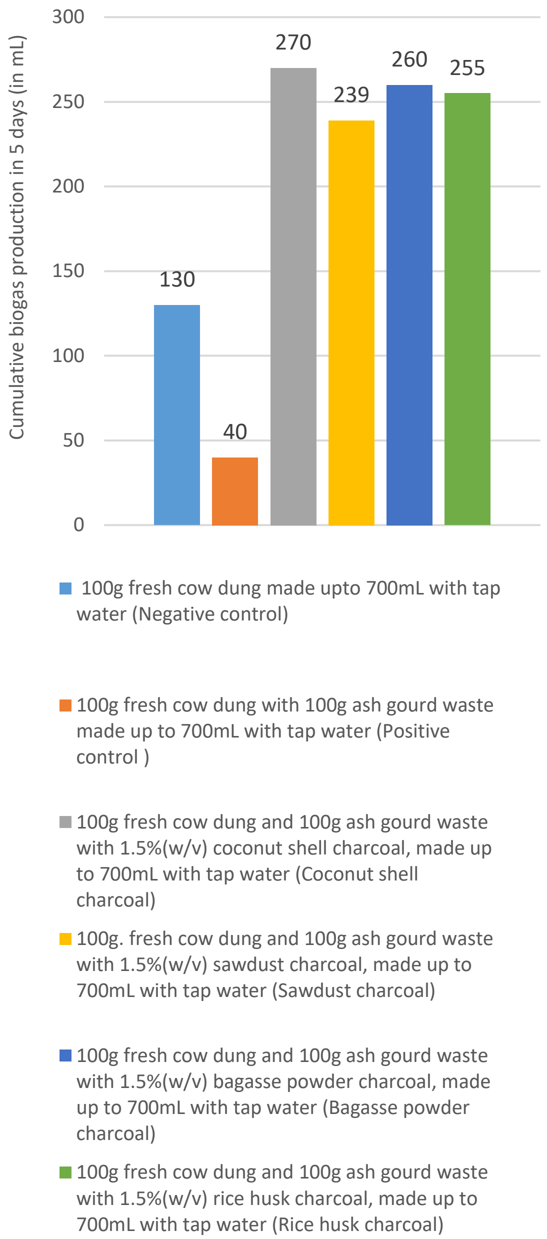


Figure 3.6. Biomethanation of rotten tomato waste with various carbon additives

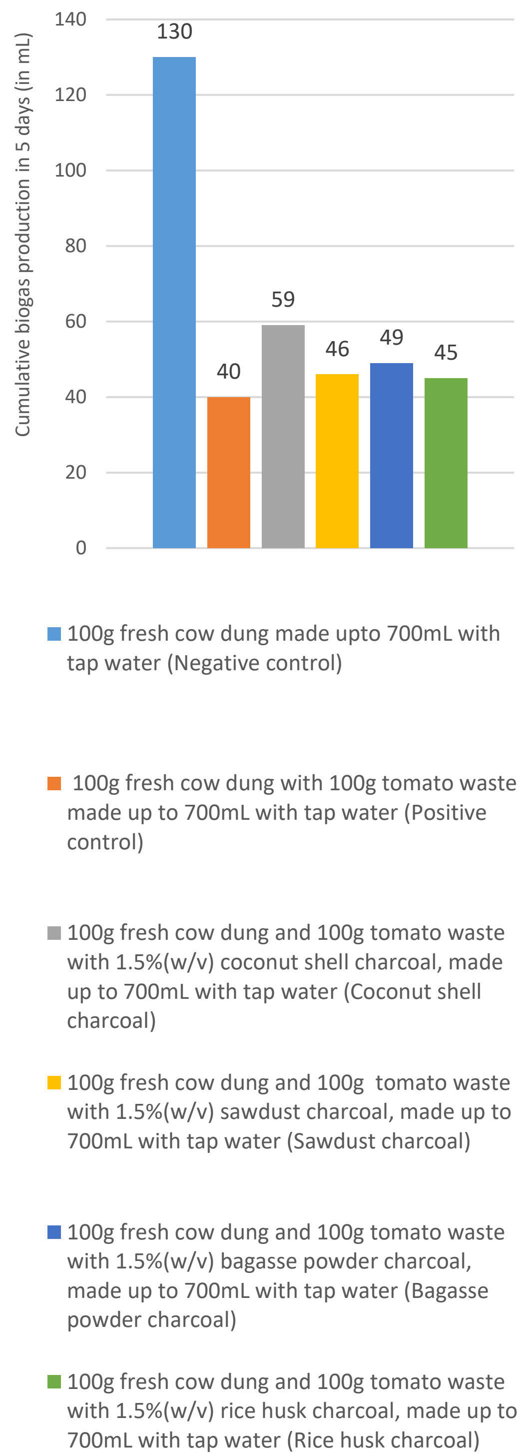


Figure 3.7. Biomethanation of rotten vegetable waste with prawn peel powder supplementation in the presence of coconut shell charcoal

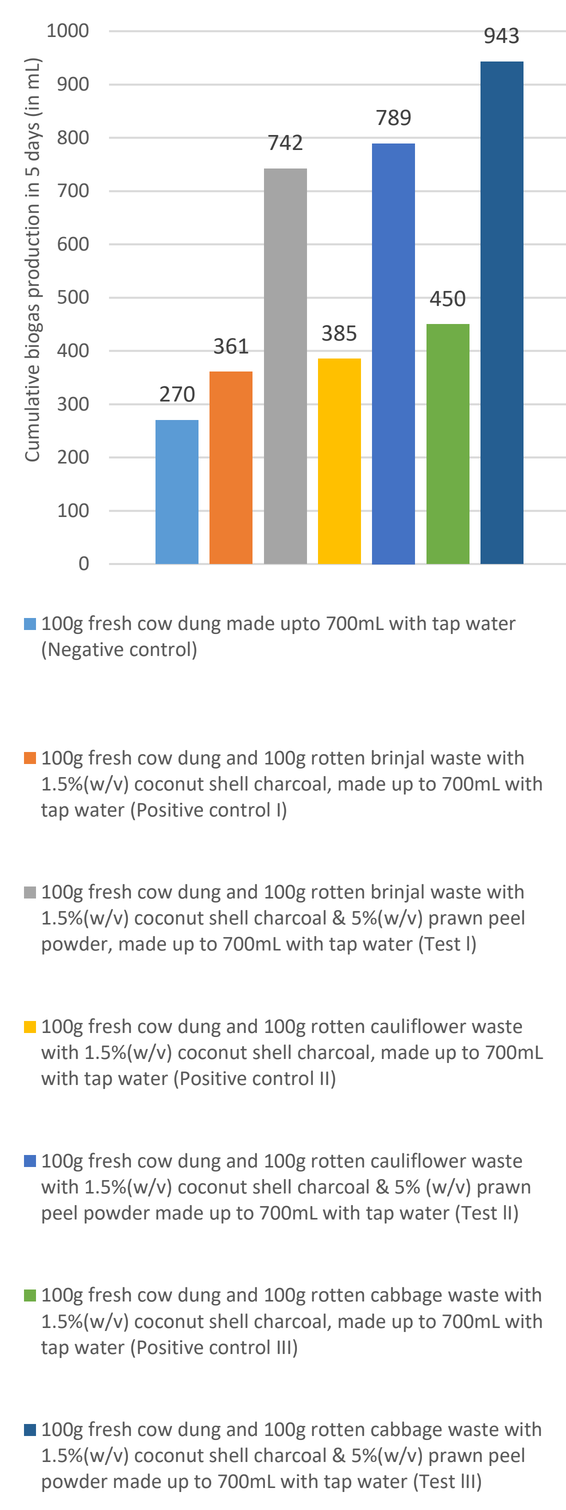
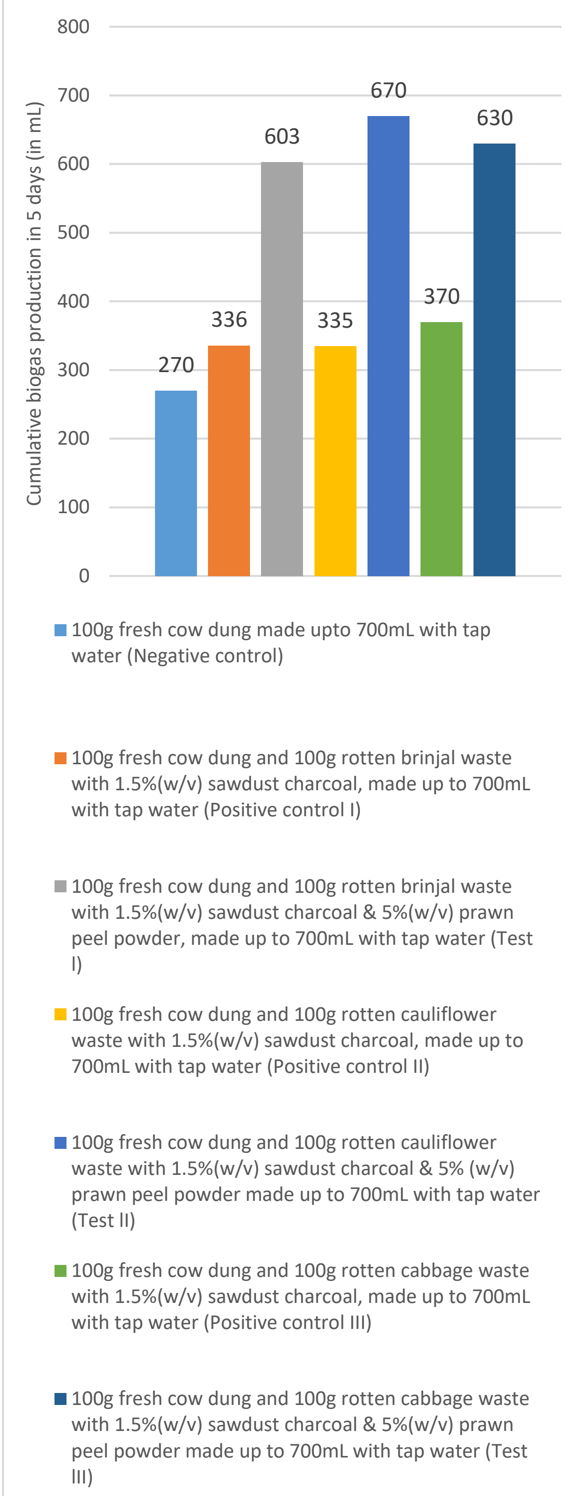
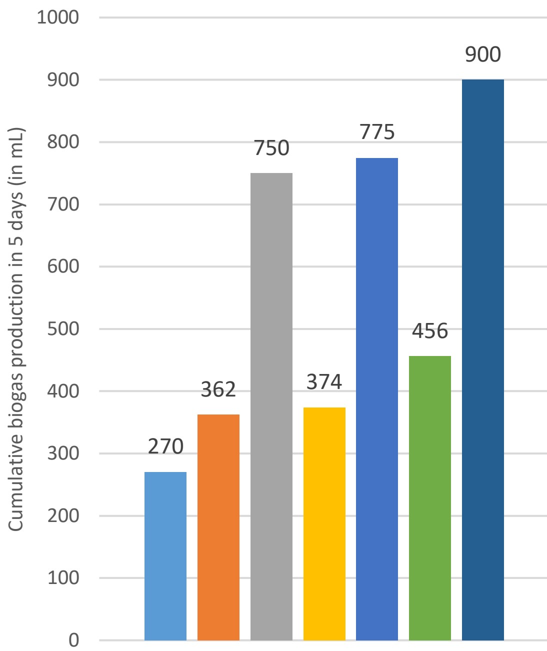


Figure 3.8. Biomethanation of rotten vegetable waste with prawn peel powder supplementation in the presence of sawdust charcoal

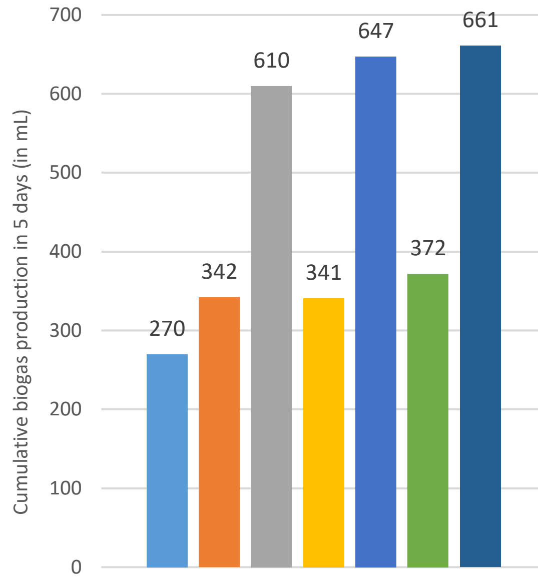


3.9. Biomethanation of rotten vegetable waste with prawn peel powder supplementation in the presence of bagasse powder charcoal



- 100g fresh cow dung made upto 700mL with tap water (Negative control)
- 100g fresh cow dung and 100g rotten brinjal waste with 1.5%(w/v) bagasse powder charcoal, made up to 700mL with tap water (Positive control I)
- 100g fresh cow dung and 100g rotten brinjal waste with 1.5%(w/v) bagasse powder charcoal & 5%(w/v) prawn peel powder, made up to 700mL with tap water (Test I)
- 100g fresh cow dung and 100g rotten cauliflower waste with 1.5%(w/v) bagasse powder charcoal, made up to 700mL with tap water (Positive control II)
- 100g fresh cow dung and 100g rotten cauliflower waste with 1.5%(w/v) bagasse powder charcoal & 5% (w/v) prawn peel powder made up to 700mL with tap water (Test II)
- 100g fresh cow dung and 100g rotten cabbage waste with 1.5%(w/v) bagasse powder charcoal, made up to 700mL with tap water (Positive control III)
- 100g fresh cow dung and 100g rotten cabbage waste with 1.5%(w/v) bagasse powder charcoal & 5%(w/v) prawn peel powder made up to 700mL with tap water (Test III)

Figure 3.10. Biomethanation of rotten vegetable waste with prawn peel powder supplementation in the presence of rice husk charcoal



- 100g fresh cow dung made upto 700mL with tap water (Negative control)
- 100g fresh cow dung and 100g rotten brinjal waste with 1.5%(w/v) rice husk charcoal, made up to 700mL with tap water (Positive control I)
- 100g fresh cow dung and 100g rotten brinjal waste with 1.5%(w/v) rice husk charcoal & 5%(w/v) prawn peel powder, made up to 700mL with tap water (Test I)
- 100g fresh cow dung and 100g rotten cauliflower waste with 1.5%(w/v) rice husk charcoal, made up to 700mL with tap water (Positive control II)
- 100g fresh cow dung and 100g rotten cauliflower waste with 1.5%(w/v) rice husk charcoal & 5% (w/v) prawn peel powder made up to 700mL. with tap water (Test II)
- 100g fresh cow dung and 100g rotten cabbage waste with 1.5%(w/v) rice husk charcoal, made up to 700mL with tap water (Positive control III)
- 100g fresh cow dung and 100g rotten cabbage waste with 1.5%(w/v) rice husk charcoal & 5%(w/v) prawn peel powder made up to 700mL with tap water (Test III)

3.11. Biomethanation of fish waste with carbon supplementation

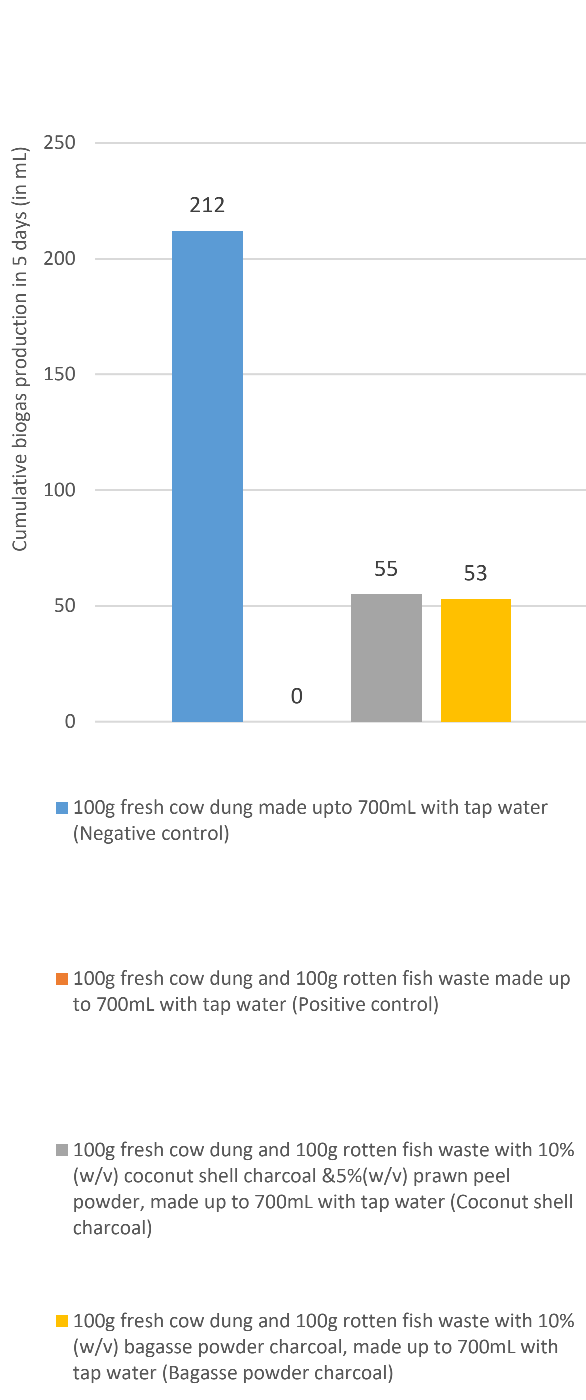


Figure 3.12. Biomethanation of poultry waste with carbon supplementation

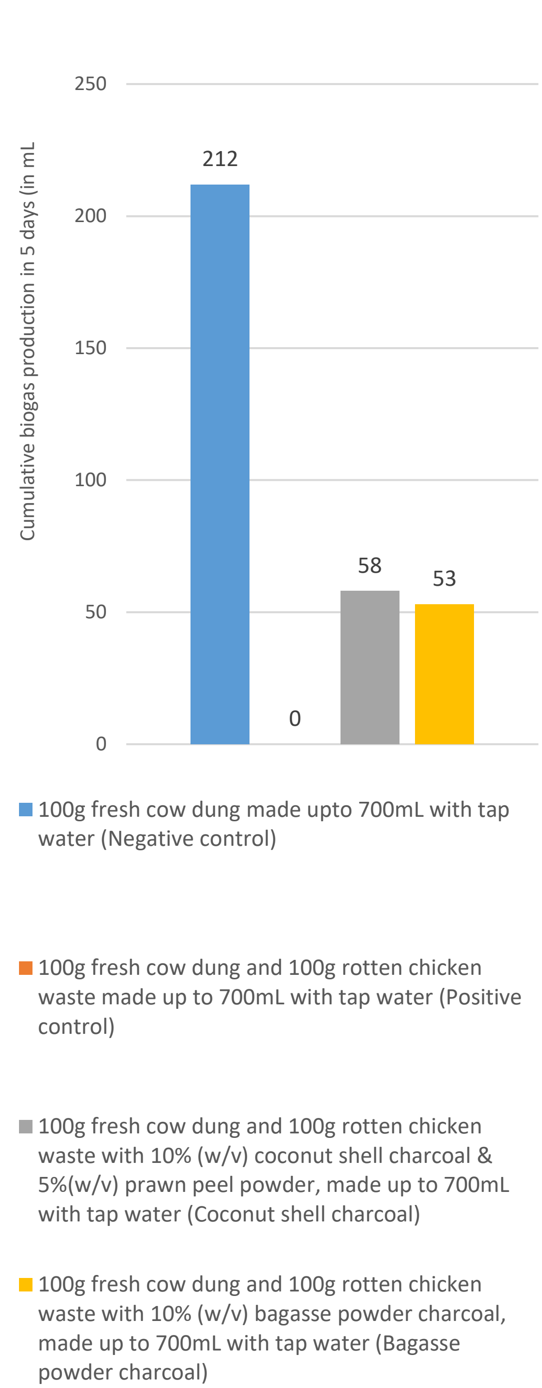


Figure 3.13. Biomethanation of lemon peel with coconut shell charcoal supplementation

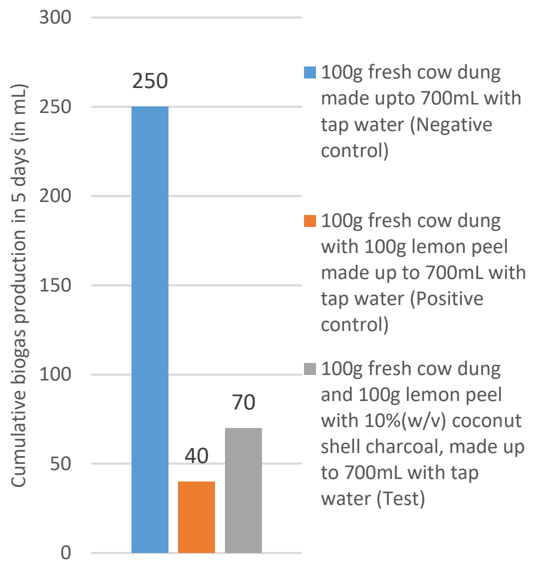


Figure 3.14. Biomethanation of mosambi peel with carbon supplementation

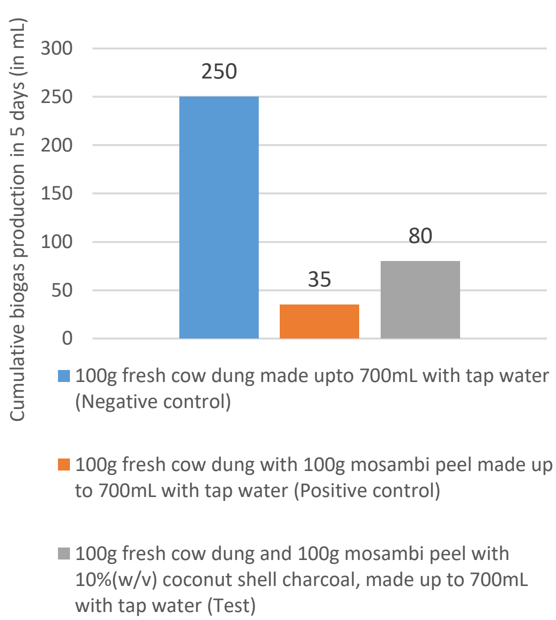
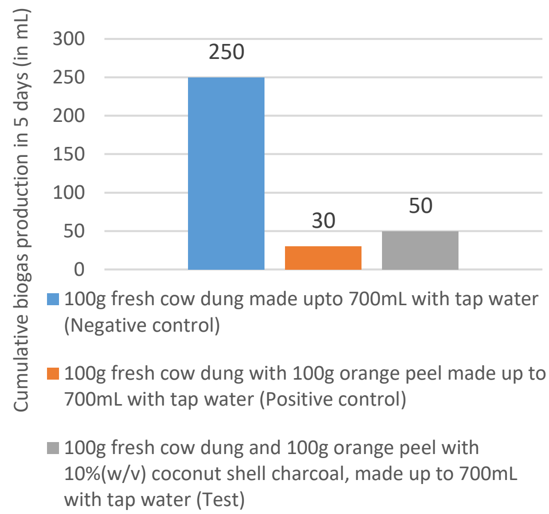


Figure 3.15. Biomethanation of orange peel with carbon supplementation



IV. DISCUSSION

Anaerobic digestion is an appealing method for organic waste and stubble resource management. The stability of anaerobic digestion is determined by the status of biochemical reactions and activities. Syntrophic, metabolic, catalytic, and enzymatic activities, among others, modulate anaerobic efficiency for increased methane generation. Access to inhibitors such as volatile fatty acids, ammonia, sulfur, and heavy metals can slow down anaerobic digestion and induce reactor failure. However, additions for various biochemical processes may help to reduce the influence of inhibitors while also improving process stability for increased methane yield (Kunvar Paritosh et. al: 2020). Carbon-based conducting materials, were reported to improve the syntrophic relation between acid formation by acidogens and methane forming microbes by interspecies electron transfer, which encompasses direct interspecies electron transfer (DIET) (Lovley, 2017). Figure 3.1 shows the bio-methanation data of different rotten vegetable wastes (brinjal, cauliflower, cabbage, ash gourd and tomato). Since each vegetable has unique biochemical composition, it gives varying amount of biogas in a fixed period of time. The figure shows the cumulative biogas production of a time period of five days with 1:1 ratio of cow dung and water slurry as inoculum. It was found that rotten brinjal, cauliflower and cabbage produced greater amount of biogas with respect to control, were ash gourd and tomato produced lesser biogas compared to control. The intrinsic pH of tomato and ash gourd is 4.6 and 6.3 respectively, this may result in the reduced yield of biogas from these vegetables. In addition, the dry weight content is less among the five vegetables, which also may be contributing to the less yield. The percentage increase in the cumulative biogas production over the period of time with respect to the positive control were respectively 42, 35, 56, 30 and 83 % for tests I, II, III, IV and V.

Carbon additives can play a significant role in enhancing biogas production by improving the digestion process. These additives, such as carbon-rich materials like biochar, can provide a surface for microbes to attach and thrive, increasing microbial activity and aiding in the breakdown of organic matter. Additionally, carbon additives can help to balance the C/N ratio in the digestion process, promoting a healthier microbial community and preventing the accumulation of ammonia (Yuan, X., Xu, T., He, L., Li, Z., Zhou, Y., & Li, Y. in 2020) Carbon additives, can further support and enhance DIET in biogas production systems. These additives provide a conductive surface for microbial attachment and growth, promoting direct electron transfer between microorganisms. Carbon additives can also help to adsorb inhibitory compounds and create a favorable microenvironment for the microbial community involved in the DIET (Zhang, D., Zhang, L., Xue, G., & Chen, C. in 2018).

Coconut shell charcoal includes carbon-rich material that can be used as an extra substrate for anaerobic digester bacteria. Bagasse is the fibrous waste left over from the processing of sugarcane. The presence of bagasse powder charcoal can promote the growth and metabolic activity of the microbial community, resulting in increased biogas production. Sawdust charcoal is composed of lignocellulosic material and is derived from wood. The lignocellulosic structure can act as a complicated carbon source, promoting the growth of a wide variety of microorganisms within the digester. The outer coating of rice grains is used to make rice husk charcoal. It’s high in cellulose and hemicellulose, which anaerobic microorganisms may easily breakdown. Rice husk charcoal can supply readily available carbon molecules, encouraging microbial activity and biogas production. Figure 3.2 shows the bio-methanation data of rotten brinjal waste in the presence of coconut shell charcoal, bagasse powder charcoal, sawdust charcoal and rice husk charcoal. It was found that in all cases there were good increase in biogas production with bagasse powder charcoal gives high yield of 11% increase. Rice husk supplementation resulted in 5% increase and 9% increase upon supplementation with coconut charcoal. Bagasse powder charcoal can be made using bagasse which is a byproduct of sugar processing industry. Since India is the second largest (22% of total production) sugarcane producers in the world, there is ample availability of this raw material which can be converted to bagasse powder charcoal in a cost-effective way. Usual problem encountered in vegetable waste bio digesters is acidic drift, which is the accumulation of volatile fatty acids, bagasse powder charcoal effectively controls this problem and make digester run in a continuous basis. In the context of global warming this technology assumes great importance for the efficient conversion of organic waste into biofuel, biofertilizers, creating a cleaner environment and mitigating carbon emission. Figure 3.3 shows the bio-methanation data of rotten cauliflower waste with various carbon supplements. In this case also it is found that the highest yield is by coconut shell (23%) charcoal and bagasse powder charcoal (21%). Saw dust charcoal supplementation resulted in 7% increase and 10% increase in samples with rice husk charcoal. Figure 3.4 shows bio-methanation data of rotten cabbage waste with various carbon supplements, the results being similar to the data produced by rotten brinjal and cauliflower waste with higher yield by bagasse (27%) and coconut shell charcoal (26%). Figure 3.5 shows the bio-methanation data of rotten ash gourd waste, it is found that bagasse powder charcoal (16%) and coconut shell charcoal (20%) produce high yield. The positive control yield is less than the negative control may be related to the inherent pH (6.3) of the vegetable. Figure 3.6 shows the bio-methanation data of rotten tomato waste. In this case the yield of biogas in the presence of different carbon sources is relatively less compared with other vegetable wastes, it may be due to the high acidity of participating vegetable. At the same time compared to positive control there is enhancement of biogas production with addition of bagasse powder charcoal and coconut shell charcoal. The addition of huge quantities of tomato wastes in its favorable season should be restricted to avoid process instability in large scale bioreactors. Coconut shell charcoal supplementation resulted in highest biogas production (24%), followed by bagasse powder charcoal (23%), saw dust charcoal (15%) and rice husk charcoal (13%).

A 100g of brinjal waste contains 5.88g carbohydrate and 0.98g protein. Cauliflower has got 4.97g of carbohydrate and 1.92g of protein and nitrogen is very low, by the addition of prawn peel waste, the C:N ratio is being optimized which enhances the net yield of biogas from each of the substrates. From figures 3.7, 3.8 and 3.9, it is found that with prawn peel powder supplementation there is substantial increase of biogas production compared to positive control in all cases and there is more production in the case of cabbage compared to other two. In a commercial purpose coconut shell charcoal may be more effective than others. In all three cases, it is found that irrespective of substrate, bio-methanation is increased by the supplementation of prawn peel powder. In this context, channelizing huge quantity of prawn peel powder to supplement in addition to vegetable wastes is an excellent opportunity in states like Kerala, which badly suffering due to shortage of power. Figure 3.10 shows bio-methanation of rotten vegetable wastes with prawn peel powder supplementation in the presence of rice husk charcoal where the test sample with 1.5%(w/v) rice husk charcoal along with 5%(w/v) prawn peel powder supplementation could result in 90 % increase in biogas production compared to respective control samples suggesting enhancement in biogas production upon supplementation with rice husk charcoal and prawn peel powder.

Figures 3.11 and 3.12 shows the bio-methanation data of fish and poultry waste with carbon supplementation. Bio-methanation of fish and poultry waste alone usually produces reactor failure due to free and dissolved ammonia. The present study shows that in the presence of coconut shell charcoal and bagasse powder charcoal, ammonia inhibition relieved with respect to the positive control. There was an increase of 78% and 45% with coconut shell charcoal and bagasse powder charcoal respectively, proving that activated carbon have the ability to quench ammonia. Figures 3.13, 3.14 and 3.15 shows the bio-methanation data of three different citrus fruits peel with coconut shell charcoal supplementation. It is interesting to note that in the presence of coconut shell charcoal, it is able to relieve the acidity and repression caused by limonene found in lemon peel. So, there is a scope for using this additive in market wastes mixed with fruits waste, of these fruits waste a good quantity will be citrus fruits. In the case of mosambi waste, maximum inhibition is relieved and 129% biogas was produced compared to positive control.

Coconut shell charcoal is found to be a better choice for relieving the toxicity of ammonia, may be due to its high porosity. In the case of fish waste also coconut shell charcoal is found to be more beneficial in mitigating the toxic effect of ammonia. Coconut shell charcoal is also found to be the better choice for relieving acidic drift of the reactor.

V. CONCLUSION

1. Carbon additives can be effectively used to counter pH drift in anaerobic digestors fed with vegetables and fruits wastes.

2. Coconut shell charcoal has found to be the best for countering acidic drift.

3. Carbon additives has also found to be very effective in countering alkaline drift due to ammonia production in digesters fed with slaughter house wastes and fish wastes.

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