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Experimental Analysis of Anaerobic Co-digestion: Potential of Fruit Wastes

S. Sathish*, A. Saravanan, R. Suresh***, K. Saranya****, R. Sarweswaran*, G. Balaji* and S. Seralathan*†**
*Department of Aeronautical Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India
**Department of Chemical Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India
***Department of Mechanical Engineering, Annamalai University, Chidambaram, Tamil Nadu, India
****Department of Physics, Government College of Engineering, Thanjavur, Tamil Nadu, India
†Corresponding author: S. Seralathan; siva.seralathan@gmail.com

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ABSTRACT

This study focuses on converting fruit waste into usable clean energy by an innovative, cost-effective anaerobic biodigester. The biodigester is designed to anaerobically digest various fruit wastes and starter inoculums of cow dung that are locally obtained. A batch vertical digester of 1000 liters capacity built of fiber with a phonematic agitator positioned in the center is used to improve mixing. The retention time is 30 days with a substrate of banana peels co-digested with mango and papaya peels individually in the ratio of 50:50. The combined wastes generated the biogas and the total quantity of biogas generated for all combined wastes over 21 days varies between 530L/day and 480L/day respectively. In this work, banana and mango peel (waste/water) split 50:50 gives a peak yield of 530L/day. The average ambient temperatures are kept in the range of 25°C to 35°C (i.e., mesophilic range). The pH range of 6.4 to 7.8 is consistently maintained and seems to be stable. Therefore, this proposed anaerobic digester would reduce the disposal of solid waste, and it is cost-effective. After cleaning, it is observed that the combined peels of bananas and papaya contained 91.95% of the estimated biogas and methane, which can be used to solve energy issues such as electricity production and cooking purposes.

INTRODUCTION

Despite being a natural and biodegradable material, fruit waste has the potential to become a significant ecological and environmental issue. The produced market fruit waste needs to be treated carefully as it contains a lot of wasted organic materials, yet it is usually discarded into the environment (Otun et al. 2016). In addition to dietary fiber, juice-seller wastes also contain sizeable amounts of enzymes, vitamins, polyphenols, and carotenoids. To manage food and fruit waste, several bioenergy technologies have been deployed, such as gasification, hydrothermal liquefaction, and biohydrogen production (Sathish & Vivekanandan 2016). The need for hydrocracking, aqueous phase reformation, and high purification were the main challenges faced despite attaining the initial goals (Suelen et al. 2017). The first order and modified Gompertz kinetic models were used to evaluate the biogas and methane production via passion fruit peel, orange, and cashew bagasse (Budiyono et al. 2018). Economically viable methods of treating solid waste, particularly in metropolitan areas of low and low-middle-income nations, were investigated in a bid to minimize hazards to the environment and public health (Sathish et al. 2018).

Fruit and vegetable wastes are generated in large quantities in markets and are irritants in landfills due to their high biodegradability (Nidhal et al. 2022). Fruit wastes are created in several industries, including wet markets, hotels, restaurants, and housing developments (Teguh et al. 2017). The two primary categories into which fruit waste from various sources can be categorized are pre-consumption and post-consumption food waste. Biogas is produced under anaerobic conditions by bacterial processes involving the biodegradation of organic compounds (Parthiban et al. 2023). Biogas can be produced using municipal solid waste, food waste, manure waste, sewage, green garbage, agricultural, plant, or animal wastes. Methane and biogas are environmentally beneficial green fuels that are used for electricity production, transportation, and heating liquid and solid foods (Divya et al. 2015). Biogas is composed of methane, which makes up the majority of biogas, and carbon dioxide, with traces of moisture and sulfide. The production of biogas, which may be used for heating, cooking, and energy production, is the main advantage of using anaerobic digestion. Methane and hydrogen, which are produced by the waste from fruits, are the two important gases that can be used to fuel vehicles as well as produce electricity and heat. The major functions of anaerobic digestion are to recover energy from diverse organic materials and to allow for nutrient recycling during the digestion processes (Nathaniel et al. 2020). Anaerobic digestion takes place under well-controlled conditions while sludge fermentation occurs.

Hydrolysis, acidogenesis, acetogenesis, and methanogenesis are the four processes that make up anaerobic digestion. It is thought that during hydrolysis, non-soluble biopolymers become soluble organic molecules. Enzymes that facilitate the reaction are released by the hydrolytic and fermentative bacteria (Muhammad & Shuichi 2014). Long-chain carboxylic acids, glycerol, soluble carbohydrates, and amino acids are by-products of the process. Environmental variables such as pH and high or low temperatures are also some of the key determinants of the final biogas product (Qiangqiang et al. 2022). To create the best conditions for the production of biogas, municipal solid waste, and household waste must be combined (Dieu et al. 2019). Biphasic fermentation with solids content feeds utilizes a solid bed for acid fermentation and subsequent methane production to lessen the inhibition of methane fermentation by organic inputs (Farkad 2016).

Based on the literature reviews, it is understood that biogas can be produced from organic wastes such as fruit waste. This approach is significant as it utilizes one of the most accessible yet underutilized renewable energy sources in the world to produce biogas. Methane and biogas are produced because of anaerobic co-digestion of fruit wastes. Therefore, the primary goal of this study is to understand how co-digestion of fruit waste, such as banana peel combined with mango peel and banana peel mixed with papaya peel, produces biogas and methane. A floating dome anaerobic digester is used to convert organic fruit waste into biogas, and the parameters such as slurry temperature, daily biogas yield, methane percentage, and slurry pH range are investigated.

MATERIALS AND METHODS

The fresh cow dung was sourced from a local dairy farm, while the fruit trash was procured from the Koyambedu Wholesale Market Complex in the city of Chennai, Tamil Nadu. For this investigation, a one cubic meter anaerobic digester with a range of ambient temperatures was used. The process of anaerobic digestion, which began with fresh cow manure and banana peels, is now being completed using papaya and mango peel, and the waste ratio is 50/50. In the same way that banana peel and mango peel are combined in a 1:1 ratio for digestion, a similar approach is also used for papaya peel and banana peel. The anaerobic digester operates in a temperature range of 30° Celsius to 38° Celsius, and the temperature of the digested slurry is measured every day using a thermocouple linked to a digital thermometer. A pen-type pH redox meter is used to monitor pH during the digesting stages of the thirty-day hydro retention time

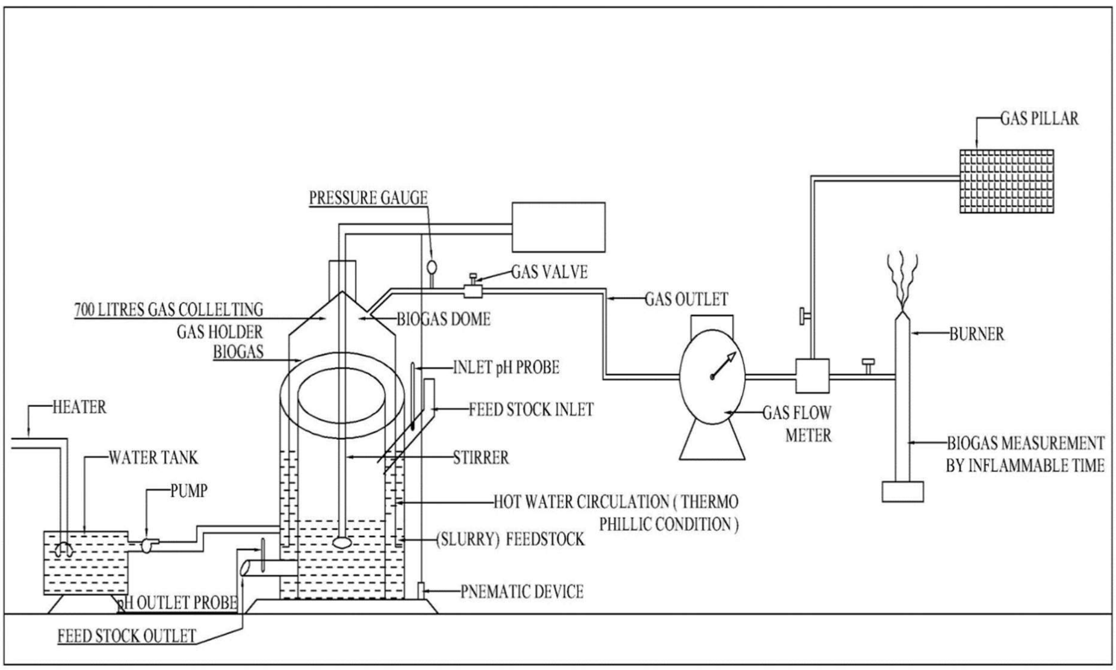

Fig. 1: Schematic experimental setup.

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(HRT) tests. The gas chromatography measured methane is examined at Nagapatinam Petrochemical Limited, Tamil Nadu, India.

A pneumatic agitator stirs the digester slurry to raise the percentage of biogas and methane during the digestion periods. The 700-litre gas-holding capacity floating dome anaerobic digester is made of fiber material. The daily biogas amount is determined by using the Albarg gas flow meter, and the digester's gas sample airbags are collected, tested, and evaluated. In the mixing tank, the digester slurry (a mixture of banana and papaya peels as well as a mixture of banana and mango peels) is made with water in an equal ratio. The prepared slurry is then supplied into the inlet chamber of the digester via the intake pipe. By feeding the new slurry, the old slurry is now pushed from the top of the input chamber into the output chamber. During the digestion time, the slurry is agitated every five minutes to eight minutes inside the digester using the stir agitation device. Fig. 1 shows the schematic view of the experimental setup.

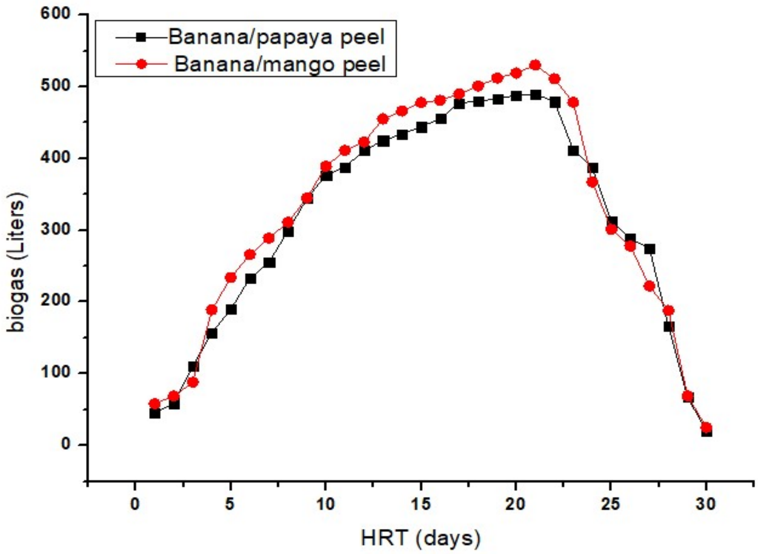

Fig. 2: Hydro retention time with respect to biogas yield.

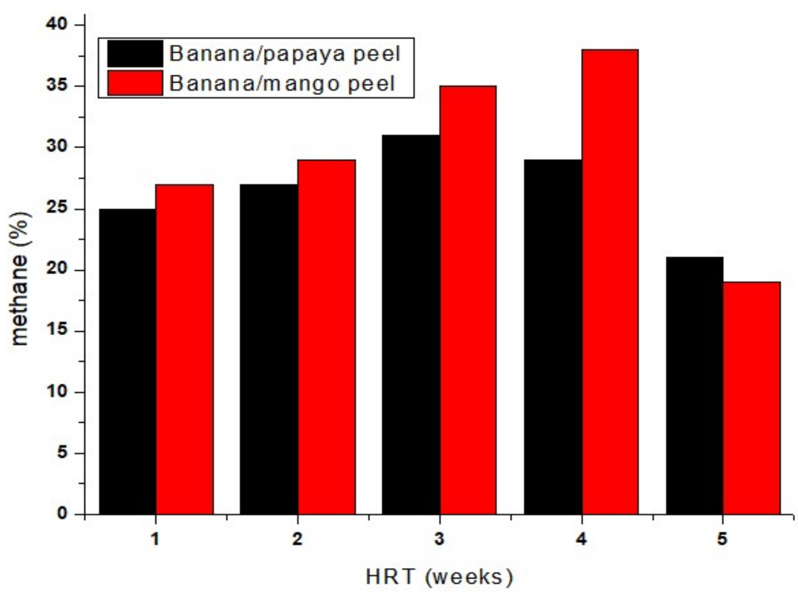

Fig. 3: Hydro retention time with respect to methane.

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RESULTS AND DISCUSSION

As a result of the hydrolysis process with banana and mango peel, it is observed that 530 liters of biogas are produced on the 21^{st} day of digestion. Fig. 2 shows the hydro retention time for biogas production. On the same 21^{st} day of digestion, the banana and papaya peels produced 490 liters of biogas. During this time, banana peels had a higher concentration of methanogenesis bacteria. Mango peels' which increased the carbon/nitrogen ratio is one of the reasons for this combination of ingredients to produce most biogas. On the other hand, the papaya peels' carbon/nitrogen ratio is under 20:1, which has an impact on the generation of biogas during the digestion process.

Bananas mixed with papaya peel and bananas mixed with mango peel have drastically different methane concentrations in biogas. Fig. 3 shows the methane percentage with respect

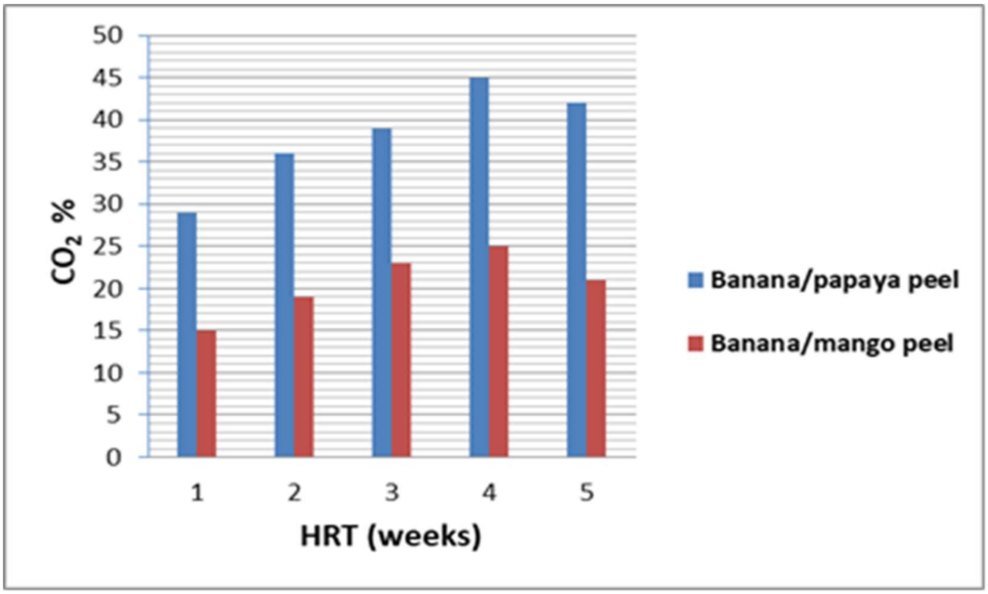

Fig. 4: Hydro retention time with respect to CO_2.

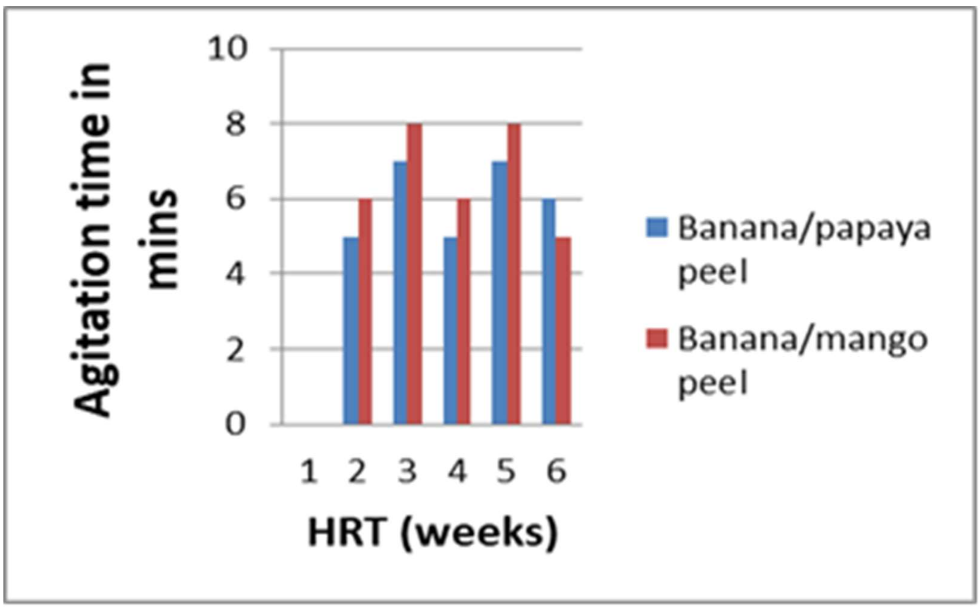

Fig. 5: Hydro retention time with respect to agitation time.

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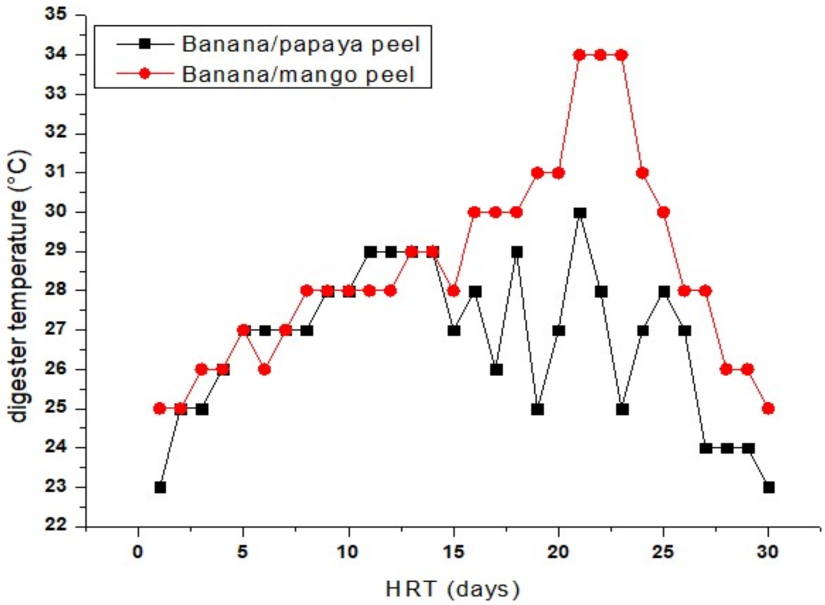

Fig. 6: Hydro retention time with respect to digester temperature.

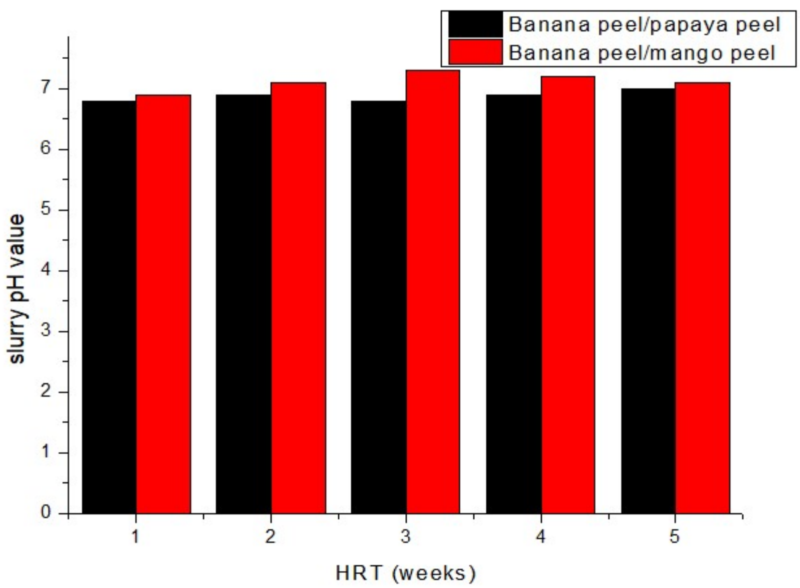

Fig. 7: Hydro retention time with respect to pH range.

to hydro retention time. At the end of the fourth week of digestion, banana mixed with mango peel produced the most methane. According to reports (Otun et al. 2016), mango peel blended with banana peel contains 38% methane. Banana peel with papaya peel has lower methane contents because of the greater alkaline base in this feedstock. Moreover, methane percentages also depend on the acetogenesis of hydrolysis products found in digester slurry.

The levels of carbon dioxide (CO_2) in biogas from banana-mixed papaya peels and banana-mixed mango peels are very different. Fig. 4 illustrates the relationship between carbon dioxide (CO_2) percentage and hydro retention time (HRT). As per the findings, the carbon dioxide levels in the banana mixed mango peels are very low during the periods of digestion. A higher percentage of CO_2 is produced when the banana and papaya peels are mixed. Due to the higher

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carbon content of banana and papaya peels, the feedstock produces most of the carbon dioxide.

It is known that to produce biogas and methane, agitation time is a crucial factor. Fig. 5 shows the relationship between the agitation time and hydro retention time. As per the findings, stirring the digester slurry for six minutes results in the highest percentages of biogas and methane compared to other stirrer timing (Seralathan et al. 2023). In an anaerobic digester, agitation encourages homogenization of the substrate, which, on the one hand, improves the contact between substrate and bacteria, speeding up the rate of organic matter degradation, and, on the other hand, prevents the formation of dead volumes, leaving particles in suspension, and which will make it easier for biogas bubbles to move around the digester.

During anaerobic digestion, temperature is one of the key parameters to produce biogas and methane. Fig. 6 illustrates the digester temperature during the digestion periods with respect to hydro retention time. The temperature of the slurry is tracked daily during the 30-day digestion period in this study. During this instance, banana mixed with mango peel produced the most amounts of methane and biogas when the slurry temperature is between 33°C and 34°C with the highest gas production being recorded on the 21^{st} day of digestion. Afterwards, biogas creation is curbed. Previous researchers (Md. Nurul Islam & Zularisam 2018) had found that methanogenesis bacteria do not form at temperatures below 28°C. Due to the low temperature, the production of biogas and methane is impacted during digestion times.

The main causes of acid production are acidogenesis and acetogenesis processes, both of which result in the production of acetic and fatty acids during digestion. Fig. 7 depicts the bio-pH digester's levels being moderated with respect to hydro retention time. In this study, mango peel mixed with banana peel had the highest pH levels of 7.1 to 7.2 during the third week of digestion and produced more biogas than other samples of papaya mixed with banana peels. Under ideal circumstances, volatile acids get converted in an anaerobic digester to methane and carbon dioxide, resulting in a pH of 6.8 to 7.2. The quantity of volatile acids produced in the digester will increase with the quantity of volatile solids fed to it. This will also increase the effect of the digester's alkalinity and pH levels. Sludge with a high volatile content should be moved gently to an anaerobic digester (Sathish et al. 2020). The ability of the reactor mixture to neutralize acids and withstand pH variations is known as the buffering capacity of alkalinity. As a result, process stability and resilience to changes in ambient circumstances are increased by buffering capacity (Vivekanand et al. 2012).

CONCLUSIONS

Based on the experimental results, it can be concluded that the banana peel mixed with mango peel can increase the daily biogas yield. Adding cow dung to fruit substrate enhances the methane and cumulative biogas yield. The process of biogas yield is not merely a source of energy but also used as a source of organic fertilizer. The anaerobic digestion of fruit waste (i.e., banana mixed with mango peels and banana mixed with papaya peels) is also the best method for managing solid waste because it lowers the quantity of waste that must be disposed of in landfills. Based on the study, the following conclusions are made.

- As a result of the hydrolysis process with banana and mango peels, 530 liters of biogas were produced on the 21^{st} day of digestion, whereas the banana and papaya peels produced 490 liters of biogas during the same period.
- At the end of the fourth week of digestion, banana mixed with mango peel produced the most methane, and stirring the digester slurry for six minutes resulted in the highest percentages of biogas and methane.
- Bananas mixed with mango peel produced more quantities of methane and biogas when the slurry temperature is between 33°C and 34°C and the highest gas production is recorded in the 21^{st} stage of digestion.
- Mango peel mixed with banana peel has the highest pH levels of 7.1 to 7.2 during the third week of digestion and produced more biogas than other samples of papaya mixed with banana peels.

Moreover, this approach produces energy in the form of biogas and generates economic benefits if the gas is used internally rather than buying energy from the distributors outside the company.

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ORCID DETAILS OF THE AUTHORS

S. Seralathan: https://orcid.org/0000-0001-6636-7794

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