Investigation of co-digestion of wastewater treatment plant sludge and plate scrap to increase biogas yield

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Abstract: This study aims to find the maximum yield of biogas by combining wastewater treatment plant sludge (WTPS) and plate scraps (PS) from Adama Science and Technology University (ASTU) student canteen. Feedstock characterization and biogas co-generation were performed using different Combinations of PS, WTPS, and cow manure in varying ratios. The individual feedstocks were evaluated for their Total solid (TS) and Moisture content (MC) before the prepared feedstock combination, and also measured combined TS, VS, Total dissolved solid (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and pH after combination of all feedstock's. These experiments were conducted in two rounds using three water baths and twenty-seven Batch Reactors (BR) with a m L volume each. These experiments were conducted in ASTU, Chemical Engineering Department at Adama, Ethiopia, to identify the biogas potential of the above-stated feedstocks. The experimental results noted that the maximum daily and total biogas yields were obtained on a composition ratio of 75% PS and 25% WTPS reactors. The daily maximum and average biogas yields were 220 and 810 ml, respectively. The average methane composition produced inside biogas was 57%. The results of a combination of 75% PSI and 25% WTPS have shown the highest biogas yield.

Key Words: Anaerobic Digestion (AD), WTPS, PS, co-generation, biogas yield

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1 Introduction

Ethiopia has abundant renewable energy resources that meet the country's present energy demands. In this respect, research on renewable energy sources is at the beginning stage. Most people from the total population living in towns and rural regions rely on traditional energy sources, such as fuelwood, dry cow dung, agricultural waste, and others. The existing Ethiopian energy system shows a large gap between urban and rural usage. Almost all rural homes cook using traditional biomass-based energy, while over 90% of urban households utilize electricity for lighting. Cooking consumes the greatest energy, with petroleum and electricity accounting for only 7% of overall energy demand . Wastewater treatment facilities in Ethiopia are essentially non-existent, and those that do exist are badly managed. Even huge cities, like Addis Abeba, experience poor drainage and wastewater overflow from businesses, institutions, and residential areas (Haddis et

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al., 2014). Ethiopian cities lack domestic wastewater treatment facilities except for Addis Ababa. As part of the World Bank's strategic sanitation initiatives, donors plan to upgrade the existing treatment plant in Addis Ababa and build urban wastewater treatment facilities in all large Ethiopian cities (GIZ, 2020). Due to fast urbanization, increased population, and water shortage, the agricultural sector is nowadays facing a great challenge. To this end, wastewater is used for irrigation, which has positive and negative impacts on the agricultural production of vegetables. Farming with wastewater has a major role in income generation, producing irrigated vegetable crops in Ethiopia and irrigating vegetable crops used as a food source and income generation for the urban community. Consuming wastewater from irrigated vegetable crops can cause diseases, e.g., cholera and typhoid, etc. (Gashaye, 2020).

Adama Science and Technology University (ASTU) has built a waste treatment plant to treat and recycle wastewater compounds, like graywater and blackwater. The wastewater plant setup is shown in Figure 1. The treatment plant has two Imhoff tanks that separate solids from liquids. The two aeration tanks are used to stabilize wastewater by removing harmful pathogens, pollutants, and poisonous chemicals. Two Dortmund tanks were used to settle sludge produced by physical, chemical, and biological processes. Coarse and small solid materials are removed with fine and coarse metal mesh screens installed at the treatment plant's inlet. The plant can treat 18,750 cubic meters of wastewater and produce around 600 kg of sludge per day. The average wastewater flow to the treatment plant is 8 liters per second. Also, the wastewater circulation of ASTU is briefly elaborated in Figure 2.

Figure 1 ASTU Wastewater Treatment Plant

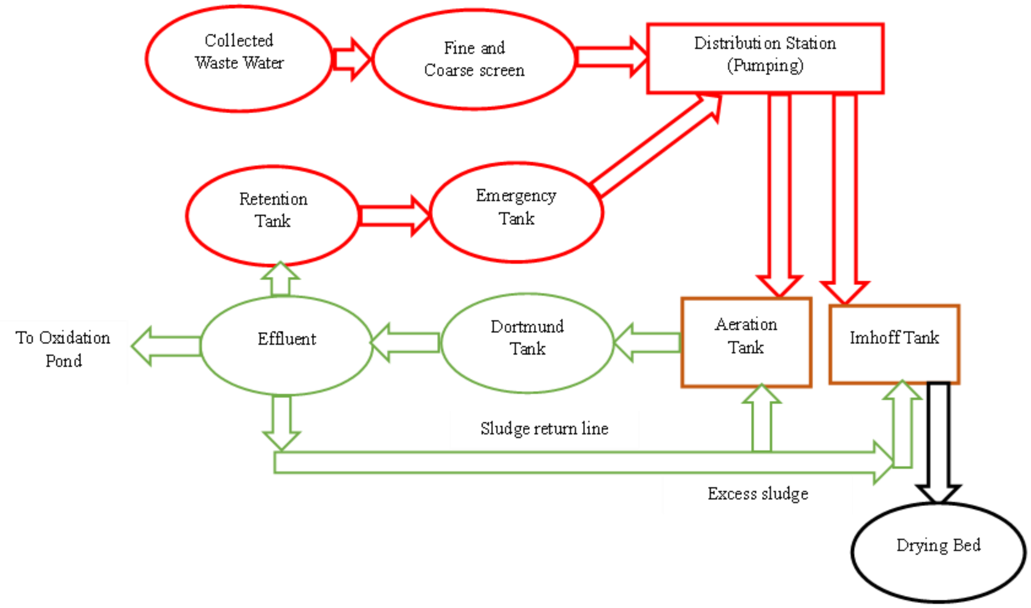


Figure 2 ASTU treatment plant wastewater circulation

Biogas is a replacement for traditional energy sources, which cause ecological and environmental issues, while depleting at a faster rate. It is a clean, eco-friendly, and renewable source of energy (Deepanraj et al., 2017; Kolhe et al, 2024). Several operating parameters can influence the anaerobic digestion process, including feedstock composition, co-feedstock mixing ratio, reactor types, and environmental factors such as temperature, hydraulic retention time (HRT), organic loading rate (OLR), pH, and nutrients (Cheong et al., 2022; Kolhe 2010).

Anaerobic digestion is a widely known process for digesting varied organic matter into usable resources. Mono digestion has different issues, like volatile fatty acid accumulation and higher organic loading. However, the co-digestion of various raw materials can overcome those constraints. Co-digestion offers the advantage of boosting digestibility through the coactive effects of co-feedstocks, improving process stability, and increasing the nutrient content of the resulting feedstock. Anaerobic co-digestion can be advantageous because it balances compounds, supplements trace elements, dilutes toxic and inhibiting molecules, and fosters the diversity of bacteria. Two or more different feedstocks are processed in anaerobic co-digestion. The characteristics of the feedstocks shall be balanced to treat them collectively. Co-digestion of food waste can generate a higher amount of biogas with the rate of fast production (Prabhu and Mutnuri, 2016). Feedstocks with combined feedstocks have improved performance over mono digestion by reducing the harmful effects of toxic compounds through dilution and increasing organic loading (Ebner et al., 2016; Kolhe, 2009). This research aims to find the best blends of biogas feedstock for co-digestion among the wastewater treatment plant sludge (WTPS) and plate scraps (PS).

2 Materials and methods

2.1 Materials

PS and WTPS are used as feedstock. A 2.5-liter plastic bottle reactor is used for the co-digestion process, and two series of one-liter plastic water bottles are used to collect the produced gas and displaced water. The reactors are batch-fed type and filled with two-liter diluted and homogenized co-feedstock and with a half-liter gas space. The detailed compositions of the used materials for biogas generation are shown in Table 1.

Table 1 Detailed composition of used materials for biogas generation

S.No	Injera, Bread, & Mixed PS, %	Sludge %	Cow manure, ml
1	25	75	100 ml
2	50	50	100 ml
3	75	25	100 ml


Muffle furnace (b) Hot air oven (c) Photo Meter (d) COD Digester

Figure 3 Scientific instruments used for characterization and experimental study

The pH, Total Solid (TS), Volatile Solid (VS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Dissolved Solid (TDS), and Moisture Content (MC) were measured with the help of different scientific instruments as depicted in Figure 3; such as a digital pH meter to measure the level of pH, hot air oven to measure TS, muffle furnace to measure VS, WTW filter photometer photo Lab® S 6 to measure COD and BOD and MC were calculated analytically.

The feedstock was taken from the canteen and the water treatment plant of ASTU. Three replications were considered for recording accurate results. Three one-liter samples are collected from each station. The size of a sample of sludge is 500 ml, and a total of 1.5 ml was collected for characterization, three for one 500 g of Injera, Bread, and mixed PS from the ASTU canteen.

2.1.1Plate scrap sample

The TS and MC of PS collected from the ASTU canteen were analyzed. Four samples were collected from two places: three samples were taken from the university student canteen, and the rest from the wastewater treatment plant ASTU. Sample feedstocks of foodstuffs like plate scraps of Injera, Bread, and mixed food items are collected from the student canteen of ASTU. The food items were collected freshly and carefully, then sorted, weighed, and packed for further feedstock characterization. The details of the prepared plate scrap sample are shown in Figure 4.

PS Injera b. PS Bread c. PS Mixed

Figure 4 Canteen samples showing plate scraps

2.2.2 Wastewater treatment plant sludge sample

Figure 5 Wastewater treatment plant sludge sample

(a)PSI with WTPS (b) PSB with WTPS (c) PSM with WTPS

Figure 6 Laboratory sample plate scrap and mixed with sludge

Samples from the wastewater treatment plant are collected from the university treatment plant, as shown in Figure 5. Methane bacteria always exist in sufficient amounts inside the Dortmund tank, so during sample preparation and digestion, the activated sludge is pumped into the Imhoff tank, and then the feedstock is collected.

2.2.3 Mixed feedstock (Plate scrap and Sludge) sample

The feedstock mixture was prepared for three types of plate scraps Injera, Bread, and Mixed plate scraps with sludge in different ratios (25:75,50:50,75:25) as shown in Figure 6.

2.2 Methods

Figure 7 describes the methods and experimental investigation path used in this research as discussed in the following steps:

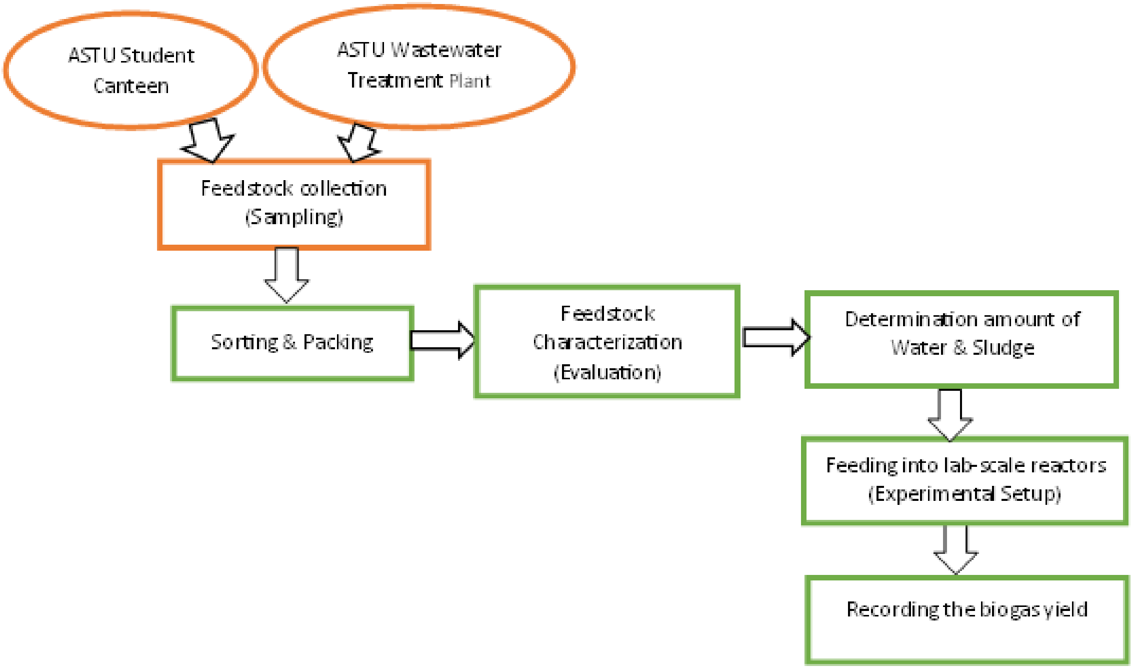


Figure 7 General research methodology of cogeneration of biogas

2.2.1 Sorting and packing

Plate scraps and wastewater treatment plant sludge were sorted carefully and packed with plastic bags after being collected from the student canteen and wastewater treatment plant of ASTU.

2.2.2 Characterization of feedstock

Characterization of feedstocks for a biogas reactor input is used to determine biogas yield, the organic matter that is converted into biogas, and the amount of water to be added to the feedstocks. The sample characterization is carried out in two steps as discussed below;

(1) Characterization of plate scraps and wastewater treatment plant sludge

Adding water dissolves the total solids within the biogas digester feedstocks. The amount of water to be added to the feedstock is determined by the feedstock's total solid content. The advantage of dissolving the feedstock's total solids is that it generates optimal circumstances for bacteria that produce methane(Wang et al., 2023; Mrosso et al., 2023). In this characterization, samples of each separate feedstock were evaluated for TS and moisture levels. Samples of food stock, such as plate scraps, Injera, bread, mixed meal items, wastewater treatment plant sludge, and 100 ml of cow manure, were examined to determine total solids and moisture content.

(2) Co-digestion feedstock characterization

Co-digestion feedstocks were analyzed for pH, TS, VS, TDS, COD, BOD, and MC. Eighteen samples were taken to the ASTU Wastewater Treatment Plant laboratory. The samples were homogenized, each a mixture of foodstuff and wastewater treatment plant sludge in various ratios. PS and WTPS used in the anaerobic digestion process were analyzed for MC, TS, and VS as per the guidelines of the American Public Health Association (APHA, 2005). TS was determined by kipping the feed stocks in a hot air oven (Make: Nabertherm, GmbH, Bahnhofstr. 20, 28865 Lilienthal / Bremen, Deutschland) at 105℃ for 24 h. The moisture content of the feedstocks was determined analytically based on the TS value obtained. VS was determined using a muffle furnace (Make: Nabertherm Compact Muffle Furnace LE 6/11/B150 LE060K1BN, Deutschland) at 550°C ± 2°C for 2 h.

2.2.3 Determination of Water to be added to the feedstocks and sludge to be added to the reactor

The required quantity of water to be added in various feedstock like PS Injera, PS Bread, PS Mixed and Sludge, and 100 ml cow manure for a fixed water temperature of 50°C, with 35 days of Hydraulic Retention Time and at 10% concentration of total solid (Indren et al., 2020) was determined by Formula (1).

$$\mathit{Water\ Required} = 100 \times TS/10 \tag{1}$$

2.2.4 Determination of the amount of sludge to be added to the reactor

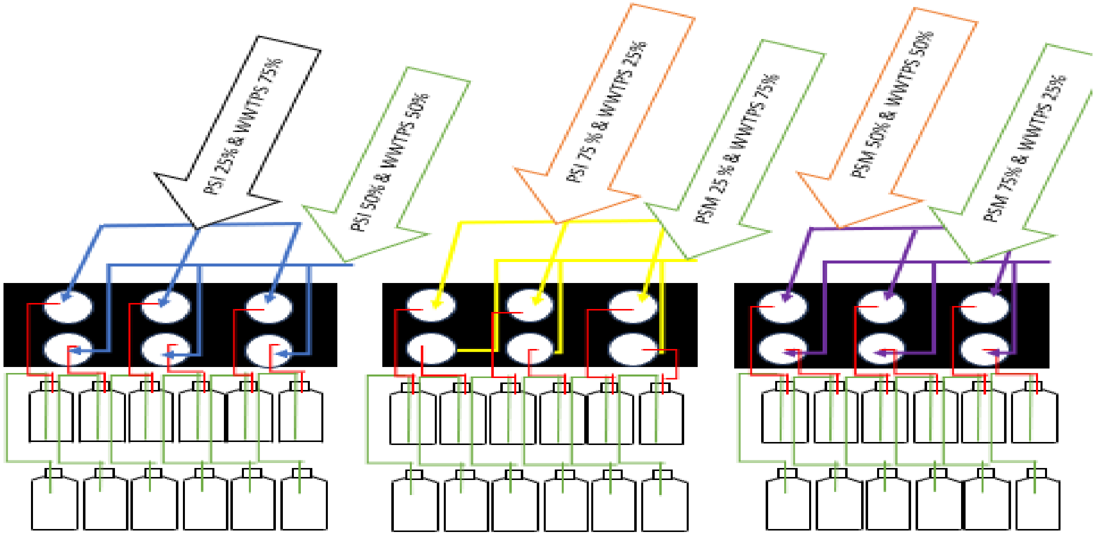
The required quantity of sludge in various mixing ratios was determined under the following conditions. TS of the feedstock and the sludge, water to be added inside the feedstock, given the ratio of mixing and the total volume of the reactor, by Formula (2).

$$\mathit{Amount\ of\ sludge} = \mathit{Solution\ of\ the\ substrate(Ratio)} \times \mathit{Mixing\ ratio\ of\ the\ sludge} \tag{2}$$

2.3 Experimental Procedure

The laboratory setup for biogas production was established at the Department of Chemical Engineering, Environmental Engineering Laboratory of ASTU, as shown in Figure 8. Three water baths were used for the experiment: two had a capacity of eight liters of water, and the third one was twenty liters, and all were equipped with automatic thermostats with digital temperature adjustment. Each water bath holds six 2.5-liter reactors and operates for 35 days continuously. The baths were filled with water once in 24 hours at a set temperature of 50°C (Thermophilic). Eighteen reactors were used for the first-round experiment, and nine reactors were used for the second round experiment, filled with two-liter feedstock mixed with different mixing ratios. Plate Scrap Injera (PSI) and Plate Scrap Mixed (PSM) with varying ratios of composition, along with Wastewater Treatment Plant Sludge (WTPS) and 100 ml of cow manure, were used to produce biogas in the first round. Plate Scrap Bread (PSB), composed of WTPS and 100 ml of cow manure in different ratios, was used in the second-round experiment. The details of the composition of the feedstock are shown in Table 2. The biogas yield was recorded twice daily from 26 Nov 2024 to 31 Dec 2024 for the first round experiment and from 2 Jan 2025 to 05 Feb /2025 at 8:30 AM and 4:00 PM. The methane gas amount in each reactor was recorded after the biogas production process was completed.

(a)Laboratory setup



(b) Experimental setup

Figure 8 Experimental set-up for Co-generation

2.4 Recording the biogas yield

The daily biogas yield was measured using the water displacement method, and total biogas yield and methane composition were measured and reported.

2.5 Recording the methane amount

Methane was recorded indirectly using an Infralyt Smart gas analyzer, which measures the amount of carbon dioxide in the produced biogas.

3 Results and discussion

3.1 Results

The TS and MC from the sample of the feedstock collected freshly are presented in Table 2. The amount of water required to dissolve the total solid of feedstock and sludge required for biogas production is presented in this section. The measured results of COD, TS, VS, TDS, and pH, and their impact on biogas yield are discussed below. The biogas yield and amount of methane inside the produced biogas are measured. Table 3 depicts the recorded quantity of water required to dissolve the total solids of the feedstock. Table 4 presents the Sludge Required for the various compositions of PSI, PSB, and PSM of the feedstock.

Table 2 TS and MC of biogas reactor feedstock before blending for co-digestion

S.No	Feedstock Sample	TS	MC
1.	PSI	43.11%	56.89%
2.	PSB	36.05%	64.05%
3.	PSM	28.51%	71.45%
4.	WTPS	2.16 %	97.84%

Table 3 Water required to dissolve the total solids of the feedstock

Feedstock Sample	TS of the Sample (%)	Total feedstock in 10 % concentration of TS	Water Required (in liter)
PSI	43.11	4.311kg	3.311
PSB	36.05	3.605kg	2.605
PSM	28.51	2.851 kg	1.851

Table 4 Sludge to be added to a biogas reactor

Feedstock	Composition	Sludge Required (in ml)
PSI	PSI 25% & 75% sludge	860
	PSI 50% & 50% sludge	690
	PSI 75% & 25% sludge	431

Feedstock	Composition	Sludge Required (in ml)
PSB	PSB 25% & 75% sludge	851
	PSB 50% & 50% sludge	721
	PSB 75% & 25% sludge	451
PSM	PSM 25% & 75% sludge	754
	PSM 50% & 50% sludge	398
	PSM 75% & 25% sludge	220

3.2 Discussions

Figure 9 depicts the total and volatile solids of a mixture of plate scrap injera and wastewater treatment plant sludge at different ratios of PSI and WTPS. The graph shows that the increase in plate scrap amount will increase the amount of TS and VS in different mixing ratios. Compared to other combinations, the feedstock combination, PSI 75% and WTPS 25%, has recorded the maximum TS and VS. The total solids of a mixture of plate scrap and wastewater treatment plant sludge increases as the amount of plate scrap Injera increases accordingly (Zhao et al., 2021). The biogas yield is directly linked with the amount of total and volatile solids that the feedstock has. Therefore, feedstock combination of PSI 75% and WTPS 25% has produced maximum yield.

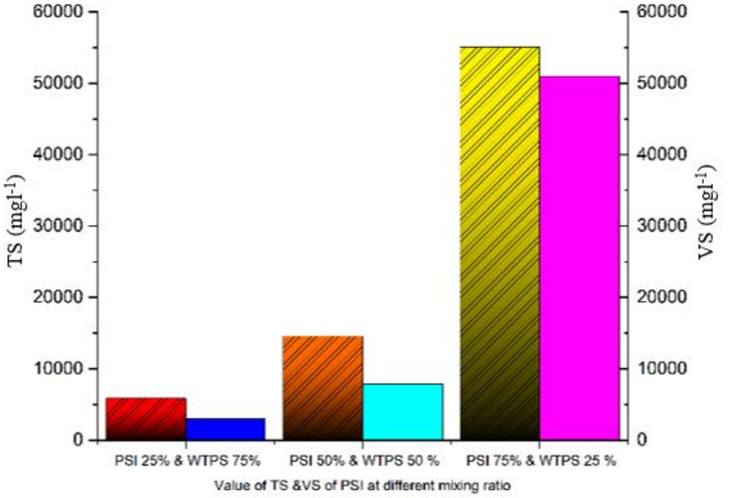


Figure 9 TS and VS of PSI at different mixing ratios with WTPS

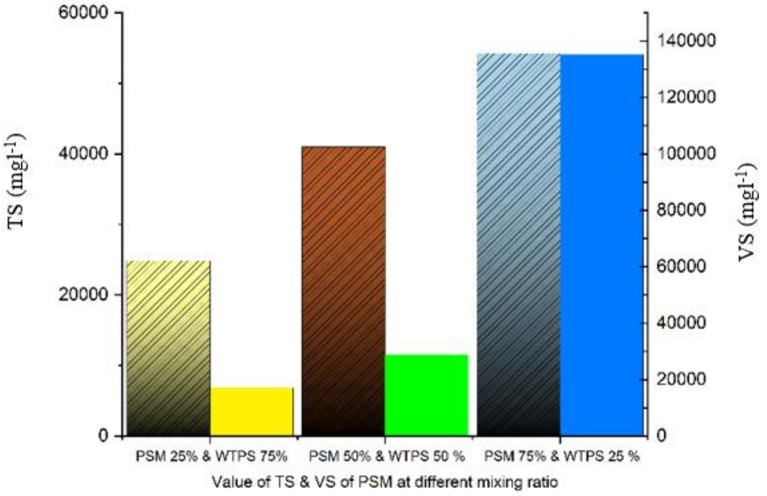


Figure 10 TS and VS of PSM at different mixing ratios with WTPS

Figure 10 shows that the feedstock PSM 75% & WTPS 25% has shown the maximum TS and VS than the others. This combination shows maximum biogas yield accordingly with the increase of the total and volatile solids. PSM 75% & WTPS 25% has produced the highest biogas yield than the other combinations of PSM.

The TS of a mixture of plate scrap bread and wastewater treatment plant sludge increases as the amount of plate scrap bread increases accordingly. The VS of the feedstock increases as the amount of PSB increases. Figure 11 shows that the feedstock PSB 75% & WTPS 25%, has shown the maximum TS and VS compared to the others, resulting in the highest biogas yield accordingly.

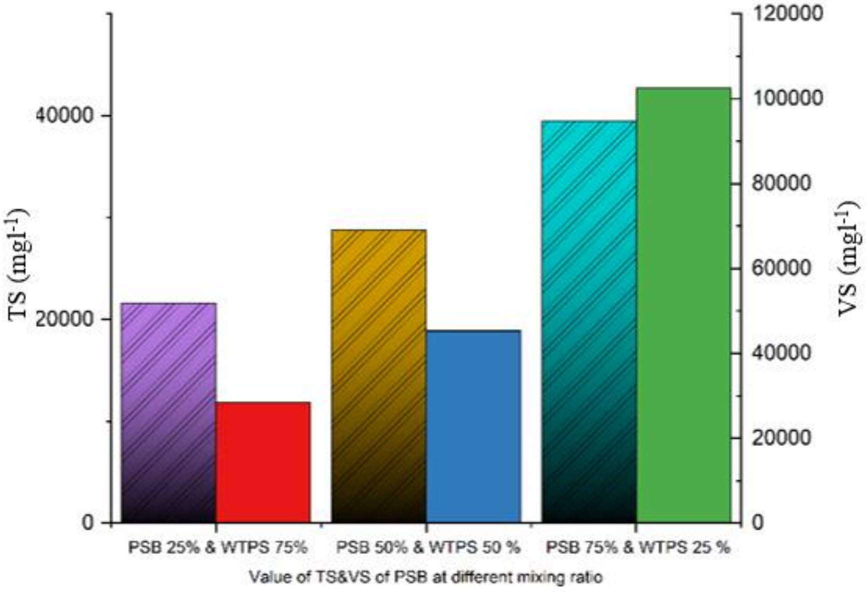


Figure 11 TS and VS of PSB at different mixing ratios with WTPS

Figure 12 depicts the chemical oxygen demand of PSI, decreasing as TS and VS increase. The more COD, the more susceptible the process is to acidic conditions during digestion. This inhibits a normal biogas production process and results in more carbon dioxide than methane. The pH is between 6.95 and 7.04, showing that the digester is in favorable condition for producing biogas.

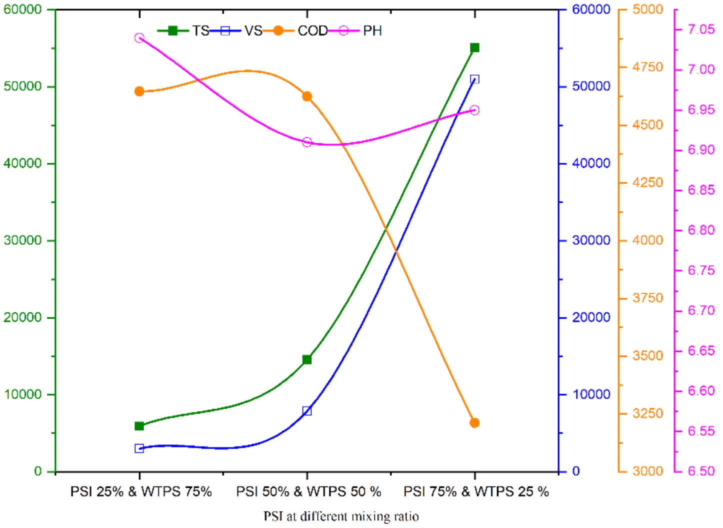


Figure 12The Influence of PSI mixing ratio on TS, VS, COD and pH

Figure 13 depicts the chemical oxygen demand of PSM decreasing as TS and VS increase. The more COD, the more susceptible the process is to acidic conditions during digestion (Srisowmeya et al., 2020). This inhibits a normal biogas production process and results in more carbon dioxide than methane. The pH is between 6.83 and 7.03, showing that the digester is in favorable condition for producing biogas.

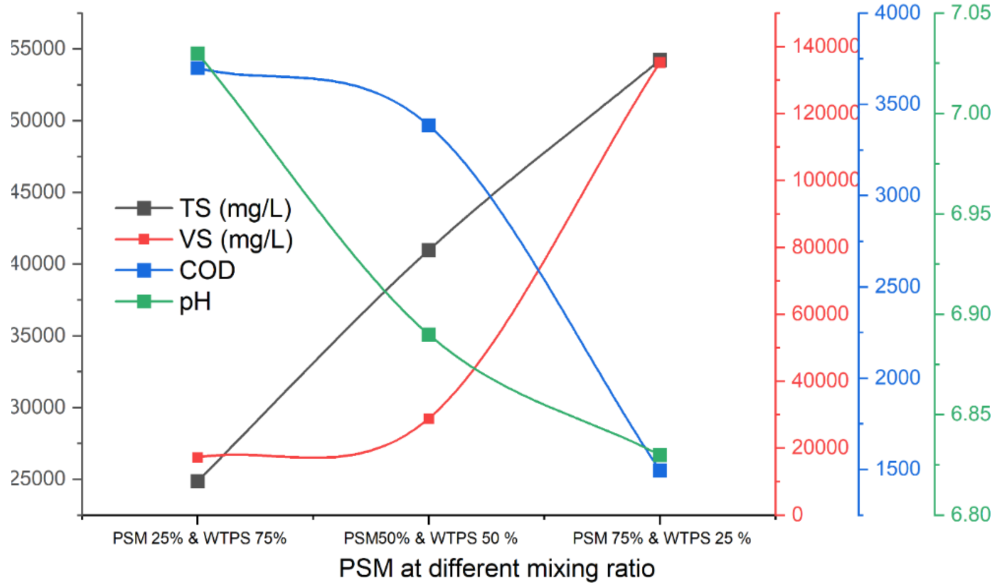


Figure 13 The Influence of PSM mixing ratio on TS, VS, COD and pH

Figure 14 depicts the chemical oxygen demand of PSB decreasing as TS and VS increase. The more COD, the more susceptible to acid conditions during digestion. This inhibits a normal biogas production process and results in more carbon dioxide than methane. The pH is between 6.51 and 6.99, showing that the digester is in favorable condition for producing biogas.

The produced biogas from all feedstocks is increasing as the percentage of plate scraps increases from 25% to 75% and the rate of wastewater treatment plant sludge decreases from 75% to 25% as shown in Figure 15.

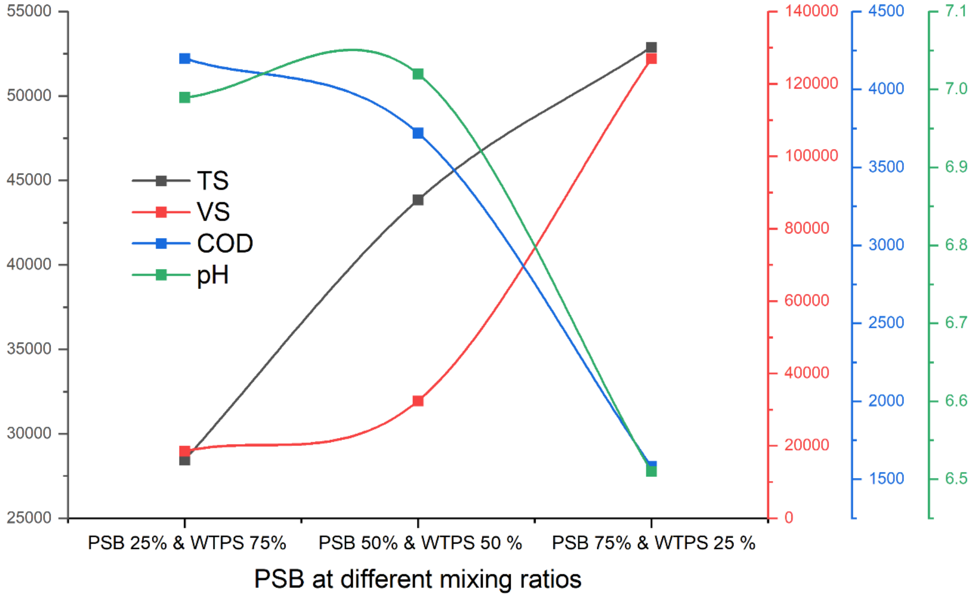


Figure 14 The Influence of PSB mixing ratio on TS, VS, COD and PH

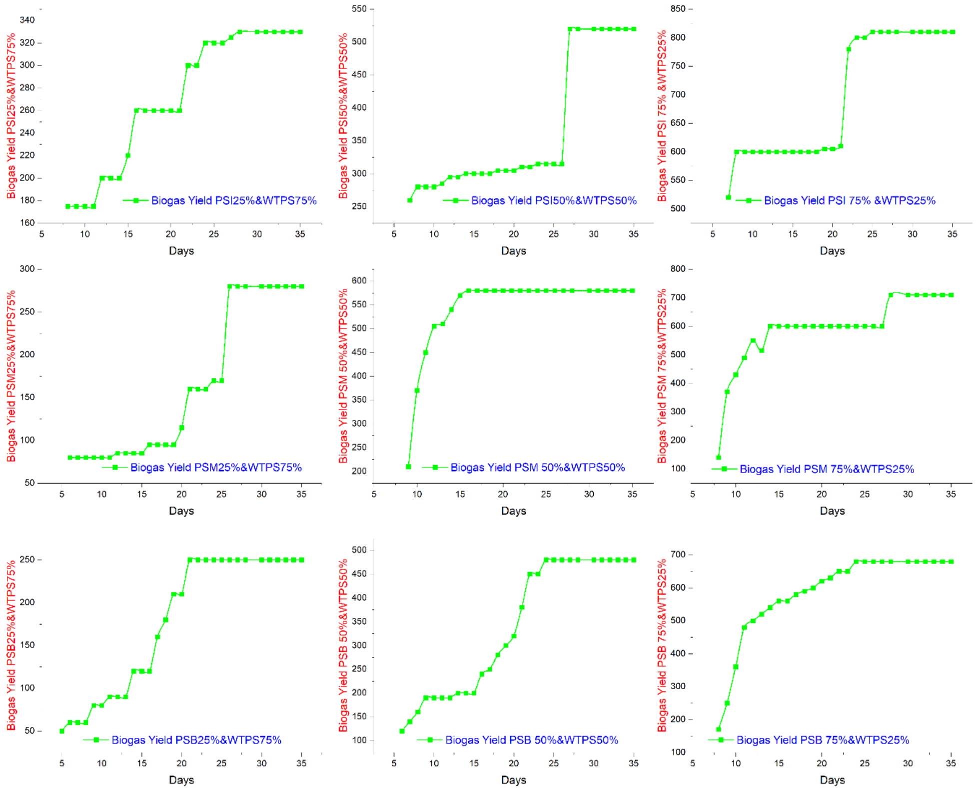


Figure 15 Biogas yield of different combination

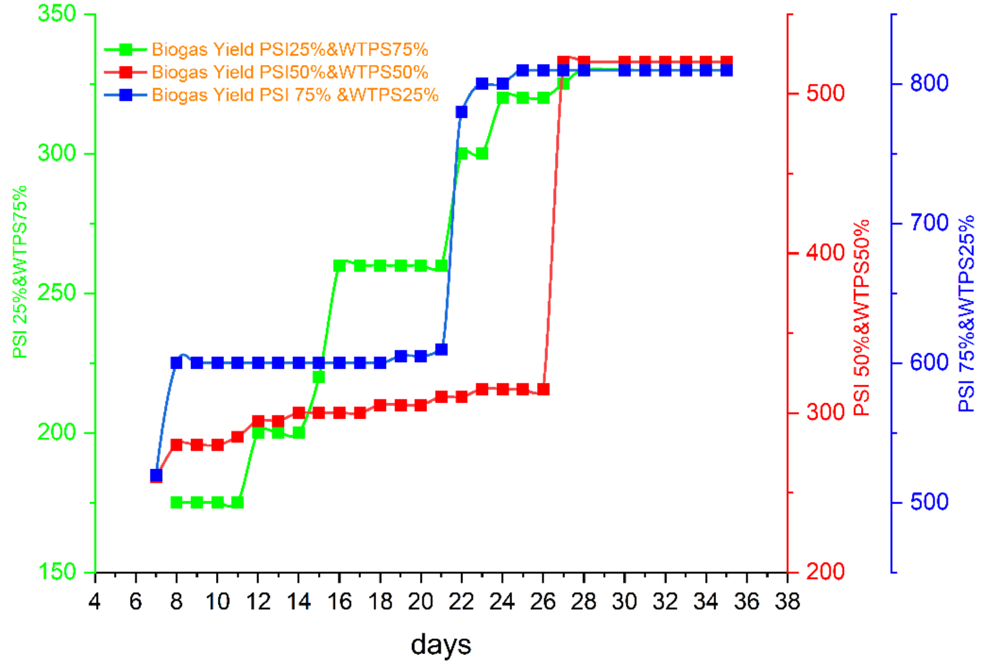


Figure 16 Biogas yield of PSI at different mixing ratios with WTPS

The combination of PSI 75% and WTPS 25% has given the highest biogas yield, but PSI 25% and WTPS 75% has given the lowest biogas yield from the Plate Scrap Injera group of biogas production process as shown in Figure 16. A group of PSI 25% & WTPS 75% began producing biogas on the 7th day, with an average of 175 ml, and maintained this rate until the 11th day. The yield continued until the 27th day, at which point it ceased production. A group of PSI 50% & WTPS 50% began producing biogas on the 7th day, with an average of 260 ml, and continued to produce until the 26th day, when it increased dramatically from 315 ml to 520 ml before ceasing production. A group of PSI 75% & WTPS 25% began producing biogas on the 7th day, with an average of 520 ml, and continued to produce until the 22nd day, when it increased dramatically from 610 ml to 780 ml before ceasing production.

The maximum biogas yield from Plate Scrap Injera is 810ml from the combination of PSI 75% and WTPS 25%. The PSI 50% & WTPS 50% group showed the highest daily average biogas yield of 205 ml of the other groups.

A combination of PSM 75% & WTPS 25% has given the highest biogas yield, but PSM 25% & WTPS 75% has given the lowest biogas yield from the Plate Scrap Mixed group of biogas production process. A combination of PSM 50% & WTPS 50% has shown the highest biogas production than PSI 50% & WTPS 50% and PSB 50% & WTPS 50% as shown in Figure 16, Figure 17 and Figure 18. A group of PSM 25% & WTPS 75% began producing biogas on the 6th day, with an average of 80 ml, and maintained this rate until the 19th day, when it was 95 ml, with a minor variance. The yield lasted until the 26th day, when it discontinued production. A group of PSM 50%&WTPS 50% began producing biogas on the 9th day, with an average of 210 ml, and lasted until the 16th day, when production ceased. A group of PSM 75%&WTPS 25% began producing biogas on the 8th day, with an average of 140 ml, and continued to generate until the 14th day, with 600 ml. The reactor stopped producing biogas from the 14th to the 27th day but increased its highest yield to 710 ml. The PSM 75% & WTPS 25% group showed the highest daily average biogas yield of 230 ml of the other groups.

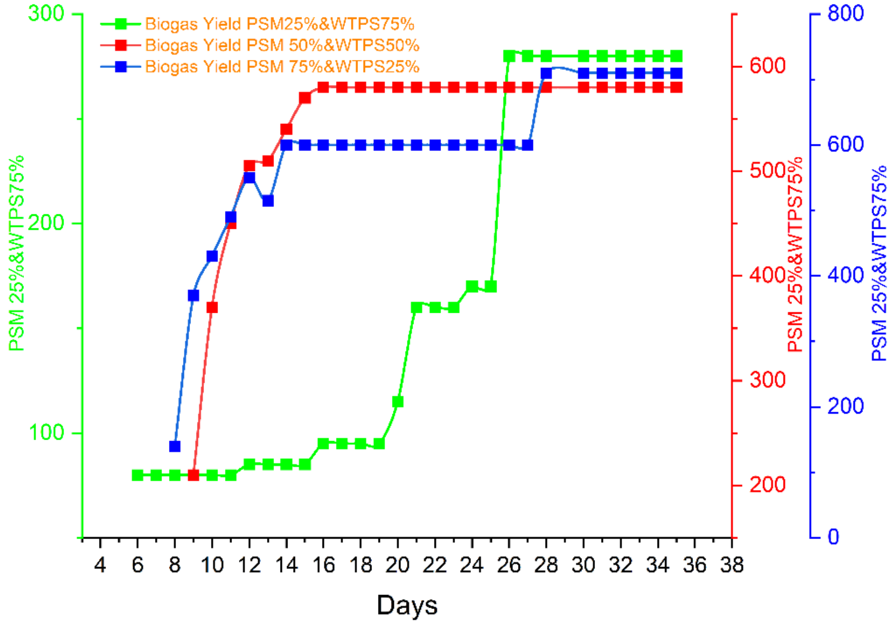


Figure 17 Biogas yield of PSM at different mixing ratios with WTPS

A combination of PSB 75% and WTPS 25% has shown the highest biogas production, but PSB 25% & WTPS 75% has shown the lowest biogas production from the Plate Scrap Bread group biogas production process as shown in Figure 18. A group of PSB 25% & WTPS 75% began producing biogas on the 5th day, with an average of 50 ml, and increased to 210 ml at the 20th day. The yield lasted until the 21st day, when it discontinued production. A group of PSB 50% & WTPS 50% began producing biogas on the 6th day, with an average of 120 ml, and continued giving the yield until the 22nd day, when production ceased. A group of PSB 75% & WTPS 25% began producing biogas on the 8th day, with an average of 170 ml, and continued to generate until the 22nd day, with 650 ml. A slight increment of 30 ml was observed on the 24th day, and no yield was recorded after day 24th, and the group's highest yield is 680 ml. The PSB 75% & WTPS 25% group showed the highest daily average biogas yield of 120 ml of the other groups.

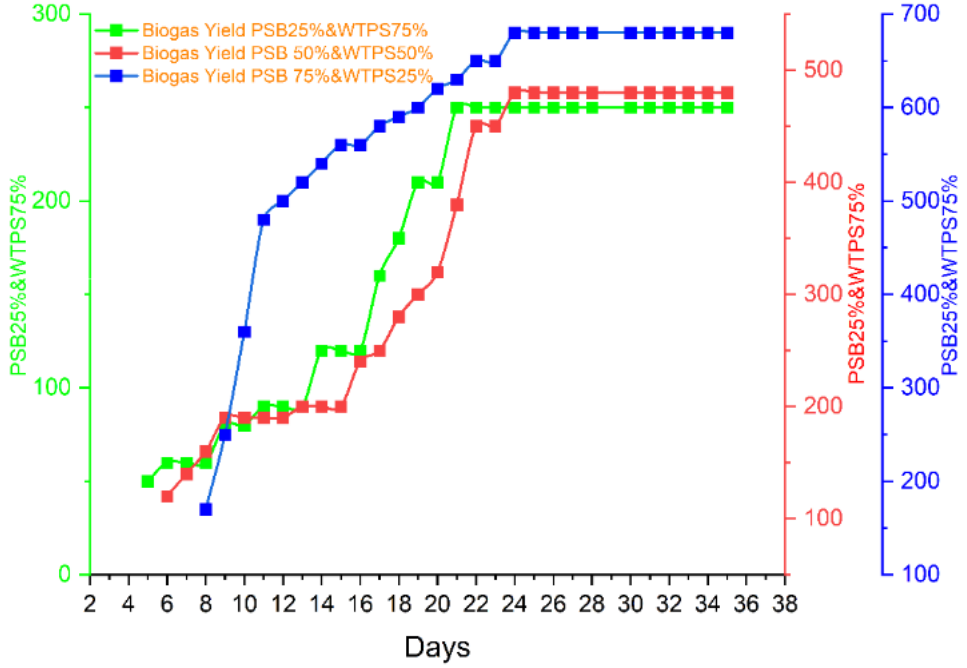
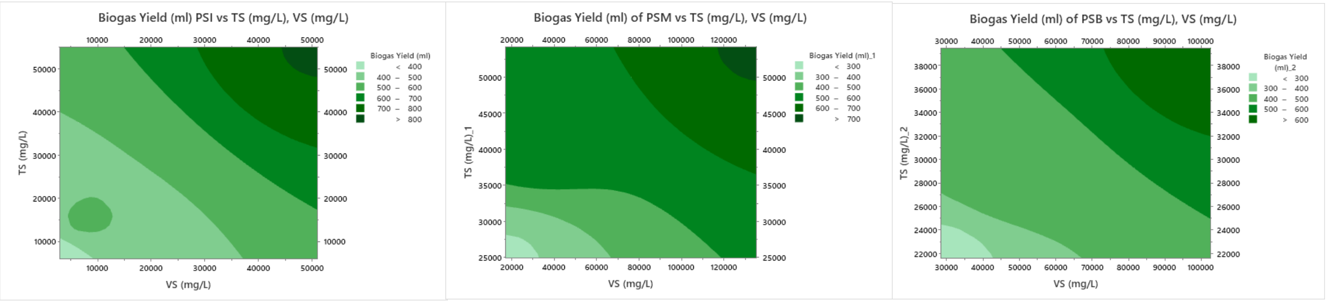


Figure 18 Biogas yield of PSB at different mixing ratios with WTPS



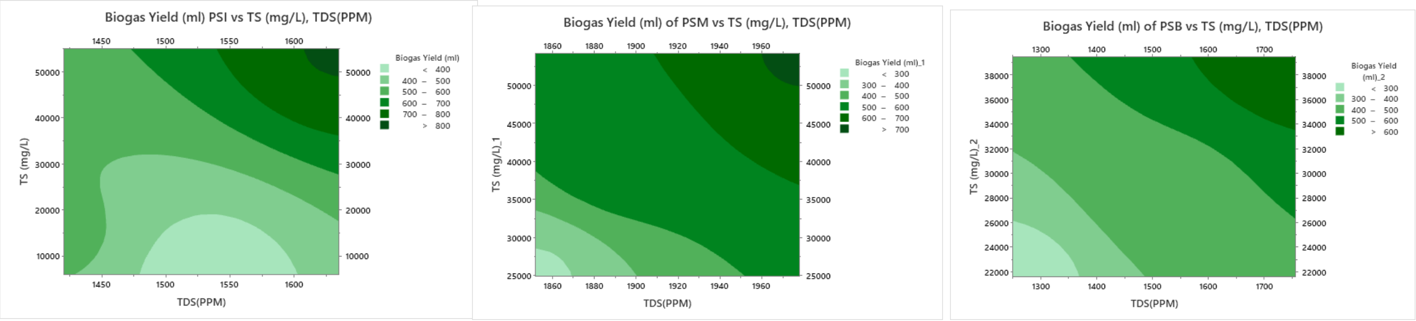
a) Biogas yield of PSI vs TS, VS b) Biogas yield of PSM vs TS, VS c) Biogas yield of PSB vs TS, VS

Figure 19 Biogas yield vs TS, VS

Figure 19 shows the impact of TS and VS on biogas yields of PSI, PSM and PSB. The higher the TS and VS, the higher the biogas yield (Wang et al., 2023; He et al., 2024). The results in Figure 19 are obtained by taking the average of the combinations of each group of feedstocks Injera, mixed food items and bread. The color change indicates the impact of both TS and VS on biogas yield in each group PSI, PSM and PSB. The obtained biogas yield of TS and VS below 1000 mg l^{-1} is from a group of combination of PSI 25% & WTPS 75%. The TS of 18,000 mg l^{-1} and VS of 25,000 mg l^{-1} were obtained from the combination of 25% PSM and 75% WTPS. For the mixture of 25% PSB and 75% WTPS, the TS and VS values were 21,000 mg l^{-1} and over 28,000 mg l^{-1}, respectively. The last, the top right deep green, shows the highest biogas yield from the group combination of PSI 75% & WTPS 25%, which the TS and VS value is over 50,000 mg l^{-1}, for PSM 75% & WTPS 25%, TS is 18,000 mg l^{-1}, and TS value is over 39,000 mg l^{-1} and VS value is over 102,000 mg l^{-1} for PSB 75% & WTPS 25%.

Figure 20 shows the impact of total and total dissolved solids on biogas yields. The higher the total and total dissolved solids, the higher the biogas yield (Abbassi-Guendouz et al., 2012). The effects of TS and

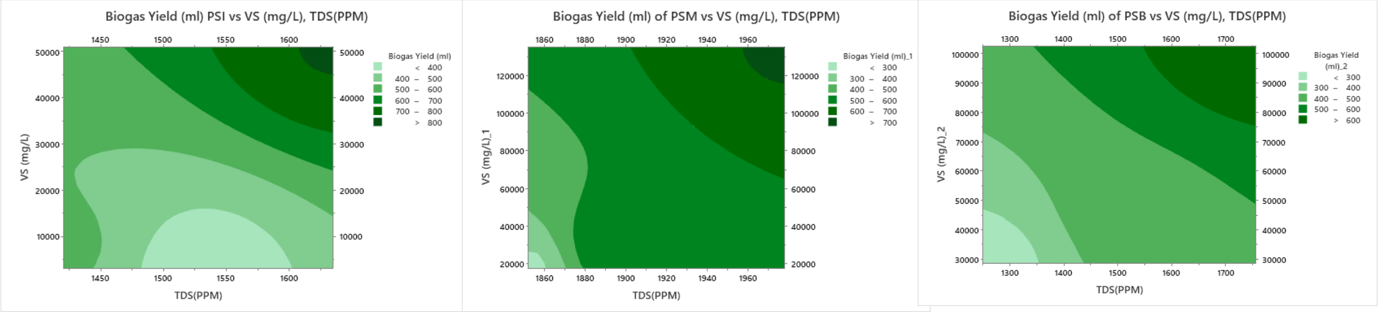
TDS on the biogas yield of PSB are less than the rest of the combinations PSI and PSM. The obtained biogas yield is shown in the figure below. The value of TS 5,000 mg l^{-1} and TDS over 1,500 ppm is from a group of combination of PSI 25% & WTPS 75%. TS over 24,000 mg l^{-1} and TDS over 1,800 ppm is from a group of combination of PSM 25% & WTPS 75%. TS over 21,000 mg l^{-1} and TDS over 1,200 ppm is from a group of combination of PSB 25% & WTPS 75%. The top right deep green shows the highest biogas yield from the group combination of PSI 75% & WTPS 25%, in which the TS value is over 55,000 mg l^{-1} and TDS value is over 1600ppm. The group combination of PSM 75% & WTPS 25% gave the highest biogas yield with the TS value over 54,000 mg l^{-1} and TDS value over 1900ppm. The group combination of PSB 75% & WTPS 25%, with the TS value over 39,000 mg l^{-1} and TDS value over 1,700ppm, has given the highest biogas yield.



a) Biogas yield of PSI vs TS, TDS b) Biogas yield of PSM vs TS, TDS c) Biogas yield of PSB vs TS, TDS

Figure 20 Biogas yield vs TS, TDS

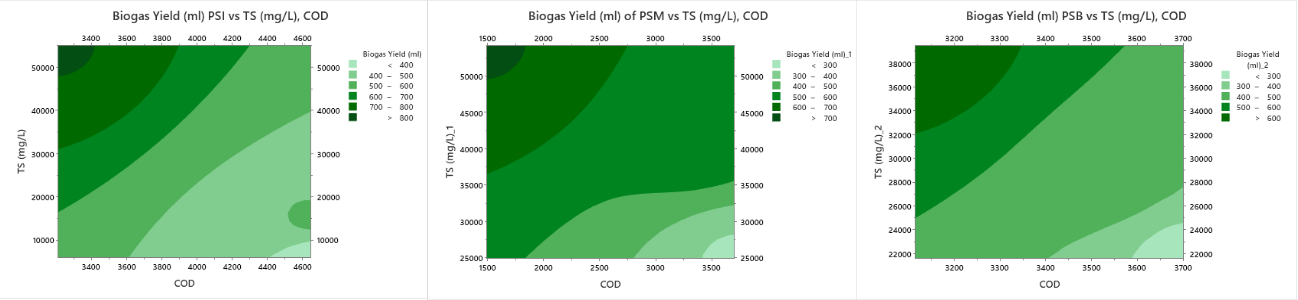
Figure 21 shows the impact of Volatile and total dissolved solids on biogas yields. The higher the VS and TDS, the higher the biogas yield. The minimum biogas yield was obtained with the feedstock combination of 25% food waste and 75% WTPS in all treatments. In PSI, the lowest biogas yield was recorded when the volatile solids (VS) exceeded 2800 mg L^{-1} and the total dissolved solids (TDS) exceeded 1500 ppm**.** Similarly, in PSM, the minimum biogas yield occurred when VS was greater than 2800 mg L^{-1} **and** TDS was greater than 1500 ppm**.** In PSB, the lowest biogas yield was observed when VS exceeded 28,000 mg L^{-1} and TDS exceeded 1200 ppm. The maximum biogas yield was obtained when the VS value was over 51,000 mg l^{-1} and the TDS value was over 1,600 ppm in a combination of PSI 75% & WTPS 25%, and also the other PSM and PSB combination showed the highest biogas yield when the VS value is over 51,000 mg l^{-1} and TDS value is over 1,600 ppm and the VS value is over 102,000 mg l^{-1} and TDS value is over 1,700 ppm respectively.



a) Biogas yield of PSI vs VS, TDS b) Biogas yield of PSM vs VS, TDS c) Biogas yield of PSB vs VS, TDS

Figure 21 Biogas yield vs VS, TDS

Figure 22 depicts the effect of TS and COD on biogas output. The increased TS and lower COD resulted in a better biogas output. The graph depicted the influence of COD and TS on biogas yield. When the TS is over 5000 mg l^{-1} and COD is over 4600 mg l^{-1}, the biogas yield is small in a combination of PSI 25% & WTPS 75%. When the TS is over 24,000 mg l^{-1} and COD is over 3700 mg l^{-1} and when the TS is over 21,000 mg l^{-1} and COD is over 3700 mg l^{-1} , the biogas yield is small too with the same percentage of plate scrap and wastewater treatment plant sludge combinations of PSM and PSB respectively. All three combinations at the 75% plate scrap ratio showed the highest biogas yield when the COD was small.



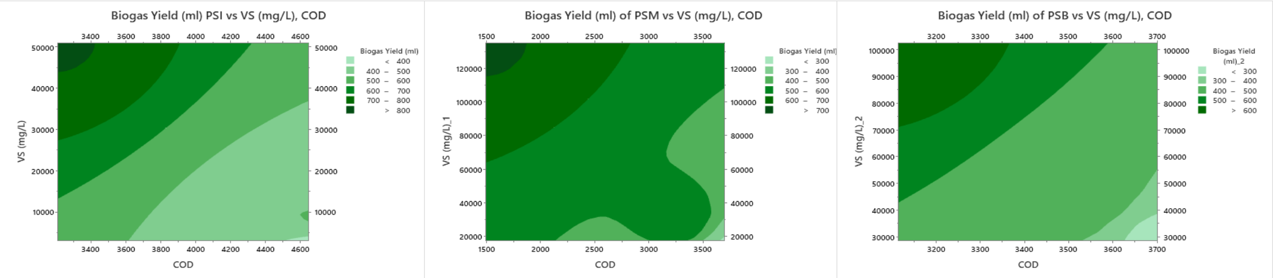
a) Biogas yield of PSI vs TS, COD b) Biogas yield of PSM vs TS, COD c) Biogas yield of PSB vs TS, COD

Figure 22 Biogas yield vs TS, COD

Figure 23 shows the impact of VS and COD on biogas yields. The higher the VS and the lower the COD, the higher the biogas yield.

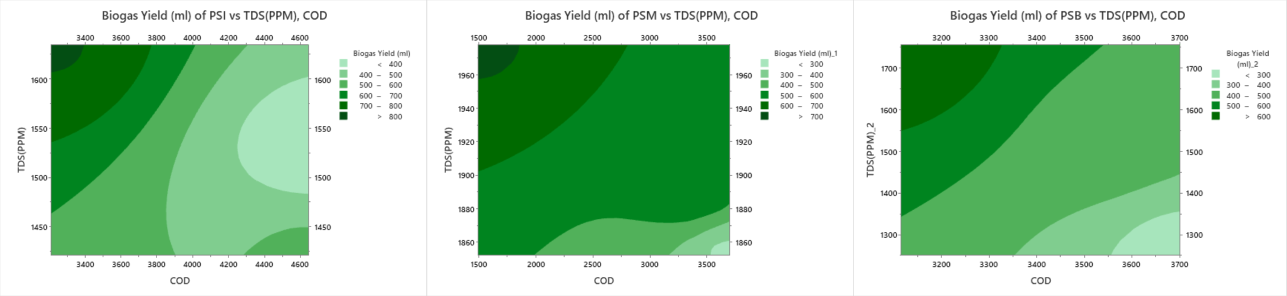
The biogas yield showed on the graph, when the VS is over 2800 mg L^{-1} and COD is over 4600 mg L^{-1}, is small in a combination of PSI 25% & WTPS 75%. When VS is over 17200 mg L^{-1} and COD is over 3700 mg L^{-1} and when the VS is over 28000 mg L^{-1} and COD is over 3700 mg L^{-1}, the biogas yield is small too with the same percentage of plate scrap and wastewater treatment plant sludge combinations of PSM and PSB respectively. All three combinations at the 75% plate scrap ratio showed the highest biogas yield when the COD was small.

Figure 24 shows the impact of TDS and COD on biogas yields. The higher the total solid and the lower the COD, will result in the higher the biogas yield.



a) Biogas yield of PSI VS, COD b) Biogas yield of PSM VS, COD c) Biogas yield of PSB VS, COD

Figure 23 Biogas yield of VS, COD



a) Biogas yield of PSI vs TDS, COD b) Biogas yield of PSM vs TDS, COD c) Biogas yield of PSB vs TDS, COD

Figure 24 Biogas yield vs TDS, COD

3.3 Measured methane

The measurement is done by measuring the amount of carbon dioxide produced using a gas analyzer indirectly. The average amount of methane from the produced biogas yield is calculated analytically, and it is noted as 57%.

4 Conclusions

In this research, feedstocks were analyzed for different TS, MC, VS, TDS, BOD, and COD before and after the digestion process. The increase in TS and VS has been noted as an increase in biogas yield within 10% of the TS concentration. The TS of sludge of the wastewater treatment plant is 2.16%, therefore, it is unable to produce enough biogas unless mixed with feedstocks that have reasonable total solids that are biodegradable and can produce biogas. Sludge from a wastewater treatment plant has very low total solids; it should be combined with other biodegradable feedstocks with reasonable total solids to produce biogas.

Canteen waste cannot produce biogas unless combined with other feedstocks that have methane bacteria, so mixing it with wastewater treatment sludge and cow manure can be a solution to produce biogas. Therefore, the co-digestion of plate scraps mixed with wastewater treatment sludge has raised the biogas yield.

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