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Optimization of Biogas Production from Avocado Fruit Peel Wastes Co-digestion with Animal Manure Collected from Juice Vending House in Gimbi Town, Ethiopia

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Abstract

Anaerobic bio digestion of fruit peel wastes is one of the potential for biogas production which subsequently reduces environmental pollution. In order to test the biogas potential of avocado fruit peel wastes co-digested with either cow dung or poultry manure, the raw materials were collected from juice vending house, dairy farm, and poultry farm, respectively. A finely grinded avocado fruit peel wastes was prepared for the different setups. The experiments include 100% avocado fruit peel wastes (T1), 100% poultry manure (T2), 100% cow dung (T3), 50% T1+50% T2 (T4), 50% T1+50% T3 (T5), 75% T1+25% T2 (T6) and 75% T1+25% T3 (T7). The total weight of the raw material was 100 g either solely or in mixture with the animal manure. 15 ml of rumen fluid collected from slaughterhouse was added into each treatment as inoculums. The total volume of the biodigesters was made 1800 ml by adding distilled water; and the setups were completely sealed in plastic bottles. The gas produced was estimated by water displacement method. Feedstocks containing both 100% poultry manure (T2) and 50% poultry manure (T4) attained maximum biogas production within 3-4 days of incubation. The highest in cumulative biogas was produced from the two treatments at 20thday. The optimum temperature, salt and pH for biogas production from the fruit wastes co-digested with animal manure were 25°C, 0.5% and 7 respectively. Under this environmental condition, the highest biogas (453.5 ± 0.5 mL) was produced by T6 that was significantly higher than the other treatments. In general, the feed stock containing poultry manure co-digested with avocado fruit waste was fast and high in biogas generation. Therefore, co-digestion of avocado fruit peel waste with animal manure is a good strategy to produce bioenergy and minimize urban solid wastes discharge although it demands controlling some physical parameters.

Keywords: Physical Parameters; Inoculum; Methanogenesis; Anaerobic bacteria; Treatment

Introduction

Energy is one of the most basic elements of the universe derived from both renewable and non-renewable sources. The non-renewable sources of energy are the major sources of pollution to environment. The renewable energy sources from sunlight, wind, water, geothermal, and biomass are environmentally friendly although it does not exist uniformly in all countries. According, to U.S. Congress, Office of Technology Assessment (1992), cooking accounts for about 90% of all household energy consumption in developing countries and 60% of the energy is from wood in the form of charcoal [1,2]. This has resulted in depleting forests at a faster rate than they can be replaced and its consequence increase average temperature by more than 1°F (0.7°C) especially since 2001 (IPCC, 2012). Particularly, Ethiopia is one of the countries that rely extremely on biomass for cooking and lighting [3].

Biogas is a combustible mix of gases produced by anaerobic fermentation of organic matter. In addition to its renewable energy source, biogas does not have any geographical limitations nor does it require advanced technology for producing energy. The generation of biogas from different types of wastes by anaerobic digestion is a method for the treatment of organic wastes in the absence of oxygen.

Biogas production from organic waste materials consists of four main stages such as hydrolysis, acidogenesis, acetogenesis and methanogenesis. The stages are interdependent on one another in such a way that the product from one stage is a precursor for the next stages and each stage involves different types of microorganisms [4]. However, biogas production depends on factors such as nature of the substrate, temperature, pH, loading rate, C: N ratio, retention time and alkalinity. These factors are known to directly affect the gas production rate and the digestion process efficacy. Besides that, organic material added as inoculums into the organic substrate [5] and the size of inoculums affected the rate of gas generation [6]. A certain amount of inoculums should be added together with the substrate to provide the required microorganisms to start the reactions in a normal start-up of a batch digester. The sources of inoculums were reported from tannery waste treatment plant, municipal waste treatment, sludge biogas reactor, and animal manure [7].

Western Ethiopia, particularly rural kebels of Gimbi town is one of the major avocado producing area. Individual fruit consumers and juice vending houses dump the peeled off avocado fruit waste in the town which is one of the major sources of environmental pollution. The lack of solid waste disposal, treatment, and reuse site is affecting beauty of the town. Particularly, avocado fruit wastes are the major contributor for the pollution although it can be reused as source of energy and organic fertilizer. Biogas production from different organic materials like Poultry [8], Chat (*Catha edulis*) waste [9] and others were performed in Ethiopia. However, the potential of avocado fruit wastes in generating biogas is not studied except the report of Leta [10] who produced biogas from mixture of avocado, papaya, mango, tomato, banana peel, and cow manure. Therefore, this research was to estimate the appropriate parameters for the optimum production of biogas from avocado fruit wastes co-digested with animal manure.

Materials and Methods

Description of the study area

The raw materials used for the biogas generation were collected from Gimbi town (9010'N, 35015' E) 441 km from Addis Ababa toward the western part of the country in the Oromia Regional State. The biogas experimental setup was conducted in microbiology laboratory of Wollega University Nekemte main campus.

Feedstock and inoculums

Three types of substrates; avocado fruit waste, cow dung and poultry manure were used as feedstock for anaerobic digestion. 1 kg of fresh avocado fruit peels wastes were purposively collected from fruit juice vending house in Gimbi town. Besides, 1 kg of both moist poultry manure and cow dung was taken from poultry farm in Gimbi town during the dry season of 2017. A 500 mL plastic bottle of rumen fluid (starting material for an anaerobic digestion process) was taken from slaughter house of Wollega University main Campus. Avocado fruit peel waste, cow dung and poultry manure were partially sun dried for three days and oven dried at 105°C for 24 h. The samples were finely grinded into 1 mm size powder [11].

Design of the experiment

A total of 100 g feed stocks was added in an anaerobic digester setup for generation of biogas in seven different combination treatment. The experiments include 100% avocado fruit peel wastes (T1), 100% poultry manure (T2), 100% cow dung (T3), 50% T1+50% T2 (T4), 50% T1+50% T3 (T5), 75% T1+25% T2 (T6) and 75% T1+25% T3 (T7) at ambient temperature was indicated in laboratory. Fifteen mL of rumen fluids was added to each digester to start up the process of digestion [12]. The experiments were conducted in triplicate and distilled water was added to the digester to make the total volume of 1800 mL. The digestion was continued until maximum biogas generation was recorded.

Experimental set up

In this study, batch mode of bench scale experimental digesters was operated for biogas production from avocado fruit peel waste and co-digestion with poultry manure and cow dung. Anaerobic digestions of substrates were carried out in plastic bottles that had plastic stoppers and each with a capacity of two litters. Three plastic bottles were arranged for an experiment in a way that the first bottle contained substrate; the middle contained acidified brine solution and the last for collecting the acidified brine solution that was expelled out of the second container [13].

All the three bottles were interconnected with plastic tubes having a diameter of 1 cm. The tube connecting the first bottle to the second was fitted just above the slurry in the first bottle to the top of the second bottle to help gas collection in to second as shown in Figure 1. Thus, the biogas produced by fermentation of the slurry was driven from the first bottle to the second bottle that contains a brine solution so as to displace a volume of the brine solution equivalent to the volume of biogas produced. The lids of all digesters were sealed tightly using super glue in order to control the entry of oxygen and loss of biogas as indicated in Figure 1 below. Manual shaking of digesters were daily performed to insure contact between the substrate molecules and microbial cells [14].

Figure 1: Set up anaerobic batch fermenter of avocado fruit peel wastes.

Evolution of physical parameters on the production of biogas

In order to test the effect of physical parameters on biogas production, the experiments were conducted at constant temperature of 25°C, 35°C and 45°C and salt concentration was 0.5%, 1%, and 3% at neutral pH i.e pH of 8.5 and 5.5.

Measuring amount of produced biogas

In order to prevent the dissolution of biogas in the water, brine solution was prepared following the method suggested by Elijah et al., [13]. An acidified brine solution was prepared by adding sodium chloride (NaCl) to water until a supersaturated solution was formed. Then, drops of citric acid from two slaves of lemon were added to acidify the brine solution. Since the biogas is insoluble in the solution, a pressure build-up provides the driving force for displacement of the solution. The displaced solution was measured to represent the amount of biogas produced. Biogas volumes were measured daily starting from next day of inoculation for about 30 days [15].

Data analysis

The data were analyzed by using spss-version-20. The effect of physical parameters such as substrate proportion, temperature, salt and pH on biogas production was tested by general linear model, univarient test. Mean comparison of the amount of biogas produced by different treatments were analyzed by one-way ANOVA using Turkey's-b at α=0.05.

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Results and Discussion

Average daily biogas production from avocado fruit peel wastes co-digested with animal manures at ambient temperature

Anaerobic digestion of avocado fruit peel wastes co-digested with either poultry manure or cow dung at room temperature for 20 days are indicated below (Figure 2). A maximum production of biogas was produced by 100% poultry manure (T2) followed by 50% avocado fruit peel wastes co-digested with 50% poultry manure (T4). The maximum production of biogas was recorded from the substrate containing poultry manure, either 100% (T2) or 50% (T4) showing the big contribution of the manure in biogas production. This is in agreement with the previous study by Yaldiz et al. [16] and Babaee et al. [17] which showed the maximum biogas production from organic wastes with mixture of poultry manure. The co-digestion of 50% of avocado fruit peel wastes mixed with 50% of cow dung (T5) produced biogas equivalent to 100% cow dung (T3). As shown in Figure 2, the production of biogas from substrate containing cow dung (T3 and T5) produced constant amount of biogas for long days. This means biogas production from poultry manure (T2 and T4) is fast and attain maximum production within 3-4 days. Whereas, biogas production from substrate containing cow dung (T3 and T5) is slow but continuous for long days. Previous research also indicated the better performance of poultry manure as compared to cow dung in biogas production [18].

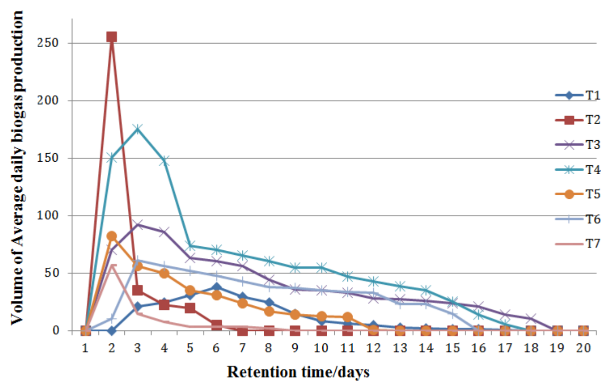

Figure 2: Average daily biogas production in ml from avocado fruit wastes co-digested with cow dung and poultry manure in batch fermentation.

Biogas production from purely avocado peel wastes started at the second day of bio-digestion and continued up to the 16th days with almost constant daily production. This could be due to high content of cellulose and lipid in avocado fruit waste which limit hydrolysis stage [19,20]. However, the substrates containing the poultry manure and cow dung started digestion and biogas production early than substrate containing the avocado fruit peel wastes alone (Figure 2). This shows the importance of the animal additive in hastening digestion and biogas production in a fermenter due to the balanced nutrients in a fermenter. In this experiment biogas production was continued up to the 18th days although the production was not uniform. In substrate containing poultry manure a sharp increase in biogas production was recorded in the first four days of start of digestion process, whereas for other substrates a uniform and continuous production was recorded (Figure 2).

Reports showed that retention time for biogas production depends on type of substrate [21]. Similarly, biogas production from T1 (100% avocado fruit waste), T2 (100% poultry manure), T3 (100% cow dung), T4 (50% T1+50% T2), T5 (50% T1+50% T3), T6 (75% T1+25% T2) and T7 (75% T1 +25% T3), were ceased on 17th, 6th, 18th, 17th, 11th, 15th, and 8th day of the batch fermentation commencement, respectively (Figure1). This could also depend on the amount and growth phase of the added rumen fluid (15mL inoculums) that might create prolonged lag phase of the methanogenic bacteria. According, to Wilki [22] quality and quantity of inoculums are critical to the performance, time required, and stability of bio-methanogenesis for the commencement of anaerobic digester.

Cumulative biogas production from avocado fruit peel wastes co-digested with animal manures at ambient temperature

The highest cumulative biogas production was recorded by T4 (50% T1 and 50% T2) followed by T2 (100% poultry manure). This means that 100% animal manure was lower in total biogas production as compared to the substrate containing avocado fruit peel waste combination (Figure 3). This could be due to the comparably more availability of biodegradable material in avocado fruit peel waste than in cow dung and poultry manure to serve as a source of energy for microbes and production of biogas [23]. On the other hand, the depletion of readily decomposable substrate and accumulation of toxic wastes due to increasing microbial population in cow dung and poultry manurecould inhibits microbial fermentation process [24,25].

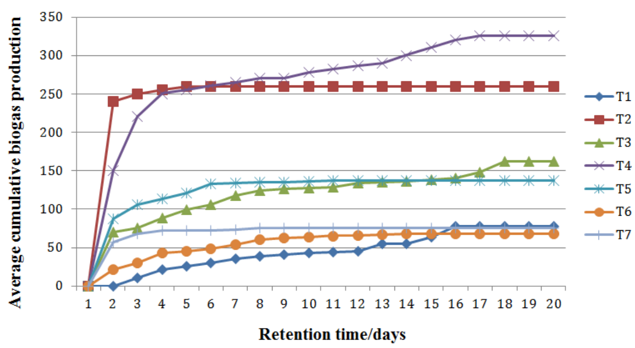

Figure 3: Cumulative biogas production from avocado fruit wastes co-digested with cow dung and poultry manure in a batch fermentation.

The next higher cumulative biogas production was resulted by substrate holding 100% cow dung and substrate containing 50% avocado peel with 50% cow dung. The other treatments produced almost equivalent amount of cumulative biogas (Figure 3). The highest cumulative biogas production from the mix of equal proportion could be due to a proper nutrient balance, increased buffering capacity, and decreased effect of toxic compounds [23,26,27].

The rate of biogas production from 75% avocado fruit peel co-digested with 25% animal waste (poultry manure or cow dung) was both slow and low in cumulative biogas production for 20 days but

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greater than avocado fruit peel waste digestion alone. In general, substrate containing poultry manure was fast in start of bio-digestion and highest in cumulative biogas production for 20 days, followed by fermenter containing cow dung (Figure 2). The result showed that selective and appropriate amount of co-digestion should be used to improve the biological and nutritive environment in the digester for microbes to improve biogas production. Muller [28] also recommended biogas production from organic substrates containing high amounts of lignin, cellulose and hemicelluloses like avocado co-digestion with animal manure or pre-treatment to enhance bio-digestion process.

Effect of temperature on biogas production

The treatment T6 (75% T1+25% T2) and T7 (75% T1+25% T3) showed the highest cumulative biogas production at 25 followed by at 35. However, the amount of biogas production sharply decreased at 45 (Table 1).

No	Temperatures levels	Cumulative production of biogas in mL	
		75% AFPW+25% PM	75% AFPW+25% CD
1	25°C	453.5 ± 0.5^{a}	281.5 ± 0.5^{b}
2	35°C	182.83 ± 1.04^{d}	196 ± 0.5^{c}
3	45°C	57.5 ± 0.5^{f}	82.5 ± 0.5^{e}

Table 1: Cumulative production of biogas in different range of temperature.

Keys: AFPW, Avocado Fruit Peel Waste; PM, Poultry manure; CD, Cow dung. The values designated by different letters were significantly different from each other at α=0.05.

This result revealed that, 25 is optimum temperature for maximum production of biogas from T6 (75% T1+25% T2) and T7 (75% T1+25% T3). Previous research also showed that the optimum temperature for biogas production from organic waste is under mesophilic range of temperature [29]. This result indicated that the methane production process is extremely sensitive to temperature change. Higher temperature could squeezes the required retention time by speeding up the degradation of organic material. Besides, methanogenic bacteria are easily affected by small temperature changes in environment [30] due to the increased inhibition of free ammonia (NH_3) which increases at elevated temperatures [31].

Effect of salt concentration on biogas production

The highest cumulative biogas was recorded at 0.5% of salt concentration for both T6 (75% T1+25% T2) and T7 (75% T1+25% T3) on the date of recording. The next higher cumulative biogas was formed for the two set up at 1% salt but highly dropped at 3% of salt concentration (Table 2).

No	Substrate composition	Salt concentration (w/v)	Cumulative biogas yield in mL		
			On day4	On day8	On day12
1	75% AFPW+25% PM	0.50%	110.33 ± 2.5^{a}	171 ± 1^{a}	202 ± 2^{a}
		1%	74.67 ± 3.05^{c}	120.5 ± 1.33^{c}	131 ± 1^{c}
		3%	60.17 ± 0.76^{d}	73.83 ± 1^{e}	73.5 ± 1.32^{e}
2	75% AFPW+25% CD	0.50%	100.5 ± 0.5^{b}	130.33 ± 1.5^{b}	155 ± 2^{b}
		1%	61 ± 1^{d}	111.67 ± 2.0^{d}	124.5 ± 1.32^{d}
		3%	32.17 ± 0.76^{e}	37.5 ± 0.5^{f}	37.27 ± 0.64^{f}

Table 2: Cumulative biogas production at different salt concentrations.

Keys: AFPW, Avocado Fruit Peel Waste; PM, Poultry manure; CD, Cow dung. The values designated by different letters were significantly different from each other at α=0.05.

It was recommended that increasing salt could cause a higher volatile fatty acid and lowers pH that slows down the microbial activity of the digester [32]. In addition, increase in salt concentration prolong lag phase of the microbial growth phase hence an increase in the length of the fermentation period [33].

Effect of pH on biogas production

The treatment T6 (75% T1+25% T2) and T7 (75% T1+25% T3) showed the highest cumulative yields of biogas at pH 7. At a pH of 8.5 a relatively the next higher biogas was produced but the production sharply reduced at pH of 5.5 (Table 3).

pH	Biogas yield from substrate composition in ml	
	75% AFPW+25% PM	75% AFPW+25% CD
7	451 ± 1^{a}	282.17 ± 1.04^{b}

8.5	278.5 ± 1.32c	230.5 ± 0.5d
5.5	120.83 ± 0.28f	180.5 ± 0.288e

Table 3: Cumulative production of biogas at different pH levels

Keys: AFPW, Avocado Fruit Peel Waste; PM, Poultry manure; CD, Cow dung. The values designated by different letters were significantly different from each other at α=0.05.

This implies that pH 7 resulted in highest biogas production followed by 8.5 and 5.5. Dioha [34] stated that methanogenic bacteria are sensitive to both high and low pH and grow better in pH range of 6.5 and 8. Specially, methanogenic bacteria are sensitive to acidic environment. The optimum pH for biogas production was in the range of 6.8-7.2 [35] similar to the present study. The growth rate of methanogens severely reduced when the pH of the biodigester is less than 6.6 [36]. An excessively alkaline pH also leads to the disintegration of microbial granules and subsequent failure of the digestion process [37,38].

Conclusion

The study showed that Avocado fruit peel waste is a potential substrate for biogas production. Poultry manure and Cow dung have been found to hasten the biodgestion process as the substrate containing the animal manure were found to produce biogas with shorter time than the avocado fruit peel waste alone. The maximum biogas (453.5 ml) was produced within four days of incubation from the feedstock containing 50% of poultry manure. Chemical factors such as temperature, pH and salt level of the feedstock has significant effect on biogas production. The maximum biogas was produced at 25°C, neutral pH and 0.5% salt. In general, biogas production from avocado fruit waste can be optimized by co-digestion with rumen fluid and animal manure. However, the bio-digestion process requires controlling of temperature, salt and pH.

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