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Characterization and Composition Analysis of Fruit Vegetable Waste Co-Digested with Buffalo Dung for Methane Production

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ABSTRACT

At present world is moving towards renewable energy resources, especially biomass. The fruit and vegetable waste (FVW) is an essential component of municipal solid waste that mostly comes from households and wholesale markets**.** The FVW is biodegradable in nature and there is no proper method to manage this type of important organic waste. This study examines the composition and characteristics of fruit and vegetable waste for suitable utilization in anaerobic digestion process to produce methane yield. The physical composition of FVW comprises of 69.59% of vegetable waste and 30.41% of fruit waste. Initially, the characteristics of FVW were analyzed for pH, total solids, and volatile solids which were 5.7, 13% and 87% respectively. The Biochemical Methane Potential (BMP) assays were performed in 500-mL borosilicate glass reactors and operated at 37 °C±1. The total alkalinity and volatile fatty acids that affect methane production in the anaerobic digestion process were analyzed at the end of batch reactors to monitor the volatile fatty acids to alkalinity ratio. The pH was found in the range of 6.6-7.1 in all reactors which is favourable for methanogens bacteria in digestion process. The specific methane yield of R3 was 212 Nml/g VS which is higher than specific methane yield of R1 and R2. The findings of this study suggests that more buffalo dung than fruit and vegetable waste produces more methane production in batch assays.

KEYWORDS: Fruit vegetable waste, Composition, Characteristics, Digestion, Methane Production

1 INTRODUCTION

The energy sector in Pakistan is presently facing with a crisis by a rising energy demand and insufficient output production. Approximately 80% of our energy requirements are still met by oil, coal, and gas. The utilization of fossil fuels has had detrimental effects on both humanity and the environment, contributing to issues ranging from global warming to air and water pollution. The term "fossil fuels" encompasses crude oil, natural gas, and coal as they all originated from the remains of plants and animals that lived inside core of earth for millions of years. Due to their origin, fossil fuels have a high concentration of carbon [1]. Roughly 80% of the global population resides in countries heavily reliant on imported fossil fuels, encompassing around 6 billion people. In contrast, renewable energy sources are globally accessible and possess untapped potential. The International Renewable Energy Agency (IRENA) advocates that 90% of the world's electricity can and should be derived from renewables by 2050. Embracing renewable energy offers a pathway to decrease dependence on imports, allowing countries to diversify their economies and shield themselves from the unpredictable price fluctuations associated with fossil fuels.

Biomass is essential type of renewable energy and present in abundant quantities worldwide including Pakistan. Fruit and vegetable waste (FVW) is organic in nature and highly degradable generated throughout the stages of harvesting, transportation, storage, marketing, and processing. Most of the fruit and vegetable waste that is generated by market are the discarded vegetables and fruits that are being rejected by public to buy because of spoiled, these ended up being discarded because of over production and excessive storage time. The FVW generation is also depended on weather and seasonal condition, in summer more waste is generated as compared to winter. Both summer and winter have different types of vegetables and fruits and they are presented in different compositions. They quickly degrade and emit a bad odor due to their nature and composition. Biomass is accessible effectively and in a substantial amount in rural and urban zones. The general population of the rural zones will not need to pay cash for the feeding material while adopting of a biogas plant. Pakistan produces around 50 million tons of crop wastes and domesticated animals and poultry liters [2].

However, characterizing FVW is essential to understand their composition, enabling informed decisions about their utilization as a resource and determining the most effective methods for proper exploitation. The nature of the waste significantly influences the overall yield and digestion process. Waste characterization can be conducted through physical and chemical methods. For solid wastes, physical characteristics such as volume, ash, moisture, weight, total solids, volatile solids, and temperature are assessed. Chemical analysis involves measuring hemicellulose, cellulose, starch, protein, reducing sugars, total organic carbon, phosphate, nitrogen, chemical oxygen demand (COD), pH, halogens, hazardous metals, alkalinity, volatile fatty acids (VFAs) and other factors. Biochemical characteristics also include examining elements such as carbon, phosphorus, potassium, sulfur, calcium, and magnesium [3]. These analyses shed light on how effectively waste can be utilized for energy production. Biological characterization identifies pathogens and other species serving as pollution markers.

Therefore, to produce biofuel and reduce greenhouse gas emissions, it becomes vital to develop the proper waste treatment technology for fruit and vegetable wastes. Utilizing fruit waste and vegetable waste as substrates is considered an effective method for biogas production. The implementation of a waste management system focused on biogas production offers a potential solution to waste-related challenges [4]. The effective production of biogas is the result of a complicated microbiological process. Anaerobic digestion is a biological process that occurs in an oxygen-deprived environment, where substances like organic waste are converted into simple compounds. During this procedure, organic substances decompose to generate biogas, a gas mixture primarily composed of methane (typically 50%-70%), and carbon dioxide and minor traces of other gases are present, which holds significant energy potential.

Moreover, co-digestion process of digesting feedstock with additional substrates that have favourable qualities alongside feedstock has been studied as a means of enhancing the stability and dependability of the biogas generation process, particularly in periods of low feedstock availability. Co-digestion can assist in buffering the pH, dilution of hazardous chemicals, microbial community diversification, and nutrient ratio balance. This study aims to analyze the physical composition and characteristics of fruit and vegetable waste which includes total solids (TS), volatile solids (VS), and pH for methane production. A neutral pH is suitable for the biogas production, as most methanogen increases at an optimal pH range of 6.8–7.2 [5]. The pH value can be increased to above optimum level by an increase in ammonia concentration which is produced during decomposition of proteins while the value of pH decreases with accumulation of VFA. Temperature control is a key challenge as it significantly affects the physicochemical and biochemical processes in AD, hence influencing economic viability and energy recovery.

2 MATERIALS AND METHODS

The substrate used in the present study was the fruit and vegetable waste and buffalo dung (BD). The fruit and vegetable waste samples were collected from wholesale markets of fruit vegetable waste in Hyderabad which were available in that season, weight of each fruit and vegetable were determined to calculate the composition of each component. The buffalo dung sample was collected from cattle farm located near Jamshoro and inoculum sample was collected from outlet tank of fixed dome biogas plant installed in Kot Muhammad Ayub Burdi Village in Hyderabad District. Fruit and vegetables were chopped and mixed properly. The characterization of samples is essential so that the quality of the substrate can be assessed and utilized in digestion process. The moisture content (MC), total solids (TS), volatile solids (VS), ash content (AC), volatile fatty acids (VFA), total alkalinity (TA) and pH were determined by employing standard methods [6].
The Biochemical Methane Potential (BMP) test is the measure of volume of CH_4 that is produced as the decomposition of the volatile solids present in the digested slurry. BMP comprises the incubation of a small amount of substrate along with the source of energetic CH_4 producing bacteria (methanogens). The BMP assays were prepared in 500-mL borosilicate glass bottles; the borosilicate bottles were used as reactors and operated at 37 °C±1. The glass bottles were then joined to the CO_2 absorption jars, which were filled with the mixed solution of NaOH and thymolphthalein. The reactor bottles were filled with 400 mL of inoculum and were hermetically sealed [5]. However, it is capable to measure the volume of methane at standard temperature (273.15K) and standard pressure (101.325 kPa) as stated by Veiga, et. al. [7]. The specific methane was measured by cumulative volume of methane and gram VS added in the reactor.

3 RESULTS AND DISCUSSION

3.1 Composition and characteristics of substrate

The FVW composition analysis helped to analyze which fruit and vegetables are present in high quantity. Vegetables were up to 69.59% and fruits were present up to 30.41%. The highest quantity was of banana 17.45% in FVW followed by potato, tomato, ridge gourd and mango, which were highly available in that season. In fruits banana was present in high quantity and in vegetable potato and tomato were high in ratio as compared to other vegetables up to 13.66% and 13.24% respectively. Some of the vegetables and fruit were also presented in very less quantity. The overall composition of fruit and vegetable waste is represented in Figure 1. However, the substrate and inoculum was initially characterised with TS, VS, MC, and pH. The pH, TS, and VS value of FVW were 5.7, 13.68%, and 86.31% respectively. While the TS, VS, and pH of buffalo dung was 16.32%, 83.67%, and 6.87. The substrate and inoculum characteristics are given in Table 1.

Table 1 Substrate and inoculum characteristics

Substrate	MC (%)	TS (%)	VS (%TS)	Ash (%)	pH
Fruit and vegetable waste	37.94	13.68	86.31	13.69	5.7
Buffalo dung	38.16	16.32	83.67	16.33	6.87
Inoculum	95.5	4.5	69	31	6.92

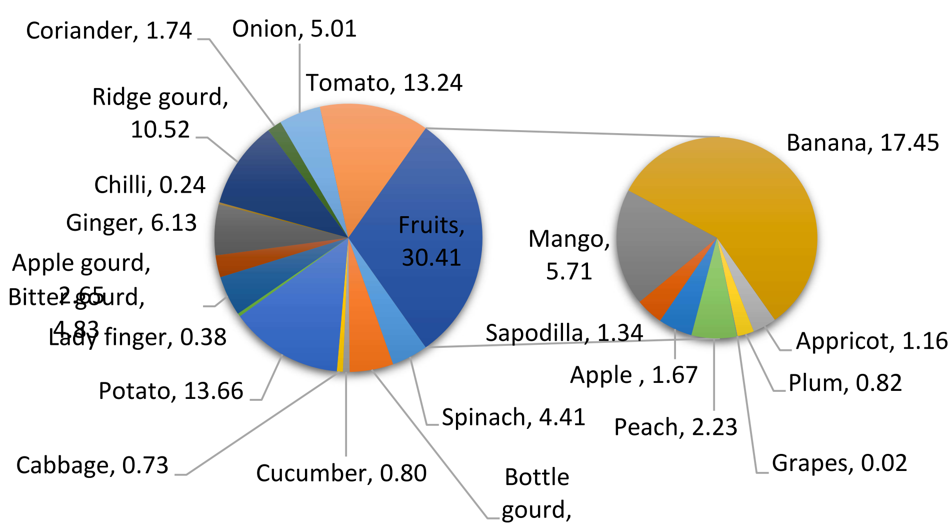

Figure 1: Physical composition of fruit and vegetable waste

3.2 Specific methane yield of substrate

The experiments were performed in BMP assays on different ratios of fruit vegetable waste and buffalo dung. The reactors for anaerobic co-digestion used in this study were R1 (FVW:BD 70:30), R2 (FVW:BD 50:50), and R3 (FVW:BD 30:70). The inoculum experiment as a control was performed and subtracted from all three reactors. The specific methane yield of R1, R2, and R3 were obtained to 160, 170, and 212 Nml/g VS respectively. The specific methane yield of R3 was higher than specific methane yield of R1 and R2 which is highly attributed by varying factors including pH, volatile fatty acids (VFA), total alkalinity (TA), and VFA/TA ratio. The pH, alkalinity, and VFA/TA ratio of R3 were 7.1, 6100 mg/L, and 0.05; whereas R1 is lower in pH value which is about 6.6 and higher in VFA/TA ratio. The VFA/TA ratio of R1 and R2 were 0.2 and 0.08 respectively which is slightly higher than R3. Therefore, the VFA/TA ratio of 0.5 or less indicates the safe working zone in the AD process [8]. The VFA/TA ratios are in fact key parameters for monitoring the stability of the digester. All reactors were stable in VFA/TA ratio which was in the range of 0.05 to 0.2 as given in Table 2.

Moreover, different pH ranges are required for anaerobic bacteria for their growth, e.g., a comprehensive pH range of 4.0–8.5 is essential by fermentative bacteria while a limiting range of 6.5–7.2 is favourable for methanogens' growth. As such, a pH value of 6.5–8.5 is essentially required for the AD process to be accomplished effectively [5].

Table 2 Specific methane yield on different ratio and characteristics of reactors

Reactor	MC%	TS%	VS%	pH	Alkalinity (mg/L)	VFA (mg/L)	VFA/TA	Specific Methane (Nml/g VS)
R1	93.9	6.1	75.1	6.6	3280	690	0.2	160
R2	92.3	7.7	64.3	7.1	5100	420	0.08	170
R3	93.3	6.7	70.3	7.1	6100	340	0.05	212

4 CONCLUSION

The exploration of fruit and vegetable waste (FVW) with buffalo dung into the production of methane through the anaerobic co-digestion has unveiled significant insights and outcomes. The physical composition of FVW indicated that the 69.59% of vegetable waste and 30.41% of fruit waste were present in waste mixture with TS content of 13.68%. In addition, the specific methane yield of R3 was perceived to 212 Nml/g VS which was higher than the specific methane yield of R1 and R2. The VFA/TA ratio of R3 was 0.05 and its pH is 7.1 which is favourable for methanogen growth. Moreover, R1 is slightly lower in pH value which was about 6.6 and VFA/TA ratio was 0.2. Therefore, the VFA/TA ratios are in fact key parameters for monitoring the stability of the digester. All reactors were stable in VFA/TA ratio which was in the range of 0.05 to 0.2. The outcomes of this study suggests that more buffalo dung than fruit and vegetable waste produces more methane production in batch assays.

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