Biogas production efficiency of park grass waste using HBT method

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Abstract: The continuous increase in global population intensifies the demand for energy. The growing need for energy has led to the ongoing search for new and renewable alternative energy sources instead of fossil fuels. Biogas energy is one of these renewable energy sources. Significant amounts of grass waste are generated in urban parks, gardens, and roadside landscaping areas. These organic wastes are often left to decay in an uncontrolled manner. Converting these wastes into biogas energy can provide added value in terms of both energy production and waste management. This study aims to determine the chemical properties [crude protein, crude fat, Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), dry matter (DM), and organic dry matter (ODM)] of grass wastes obtained from park gardens and those converted into silage, as well as their specific biogas and methane productions (m^3/kg ODM) using the Hohenheim Batch Test (HBT) method. Specific biogas and methane productions were experimentally conducted through the HBT method. The results of the study reveal that the highest protein content (17.49%) was observed in Grass 3, the highest fat content (5.13%) in Silage 1, the highest NDF (68%) and ADF (41%) content in Grass 1, the highest DM (90.92%) content in Grass 2, and the highest ODM (92.59%) content in Silage 2. The average cumulative biogas production values ranged from 0.65 to 0.71 m^3/kg ODM, while cumulative methane production values ranged from 0.39 to 0.42 m^3/kg ODM. The methane content in biogas varied between 59.01% and 60.19%. There was no statistical difference found among methane, biogas, and methane ratios derived from grass materials and silage. This suggests that either storage method - silaging or drying - can be effectively used without impacting overall biogas or methane productivity. Thus, facilities can choose between silage and dried forms based on convenience, storage requirements, or cost, knowing that both methods will perform equivalently in biogas production. This flexibility provides valuable options for optimizing feedstock management and storage in biogas operations.

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1 Introduction

Among renewable energy sources, biomass (such as biogas, biodiesel, bioethanol, biopellets, etc.) has gained significant attention due to its clean energy concept and utilization. Biomass energy can be produced directly or indirectly. It involves the combustion of existing plant or animal residues directly and their conversion into different fuels indirectly[1]. Among biomass resources, biogas technology is used to valorize waste through gasification, besides direct combustion. It is primarily utilized in Asian countries (especially China and India) and in several other countries like Denmark, Switzerland, Finland, the United States, and Germany. Biogas production is achieved through the anaerobic transformation of organic waste, mainly agricultural (plant and animal) and industrial residues, or organic waste generated by human activity. This process results in high levels of methane and carbon dioxide, along with trace amounts of hydrogen sulfide, hydrogen, and nitrogen[2,3].

Biogas, obtained in an oxygen-free environment at a certain temperature from organic waste[4,5], is a colorless, odorless gas that burns with a bright blue flame. Its composition typically includes approximately 50%-75% methane, 30%-60% carbon dioxide, and trace amounts of hydrogen sulfide, nitrogen, and hydrogen[6-9]. The density value of biogas is 0.83 g/L, with an approximate octane rating of 110, a maximum combustion temperature of 700°C, and a flame temperature of 870°C[10]. The gas ratios in biogas vary depending on the chemical content, type, and fermentation process of organic materials[10]. The production of biogas from waste not only generates energy but also facilitates waste disposal and organic fertilizer production [11,12].

The inclination and interest in biogas production stem from its ability to prevent irregular waste disposal, soil pollution, and environmental problems (odor, insect infestation, etc.), by transforming these wastes into valuable resources. Particularly, waste generated in livestock farms and regions with intensive livestock farming is crucial for biogas production. Otherwise, these wastes are left on the soil for an extended period or inefficiently burned after being converted into manure. Family or farm-scale biogas technology systems play a significant role in utilizing waste generated in rural areas. These systems not only produce biogas from fermenting animal waste but also yield efficient organic fertilizer with a high nitrogen content, reducing the formation of weeds and mitigating environmental issues. Despite the high waste utilization potential in Turkey's livestock sector, biogas technology is underutilized[13-16].

In recent years, there has been a substantial increase in urban and suburban areas, especially along roadsides, landscape areas, and parks, covered with grass in Turkey. The waste generated from these grassy areas has significant potential, yet it often goes

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unutilized. In Şanlıurfa province, according to the information obtained from the Parks and Gardens Directorate, there are approximately 980 000 m^2 of grass areas in the city center, including roadsides, landscapes, and parks. Under normal conditions, it is estimated that 1.5-2.5 kg of green grass per year is harvested from one acre of grassland. Based on this, approximately 1.47-2.45 t/a of waste grass is generated in Şanlıurfa province of Turkey[17].

Grasses are divided into two main groups based on their adaptation to climate conditions: cool-season grasses and warm-season grasses. Cool-season grasses grow within temperature ranges of 10°C-21°C, while warm-season grasses thrive in temperature ranges of 15°C-27°C. Commonly used cool-season grasses include creeping bentgrass, fine fescue, rhizomatous tall fescue, rhizomeless tall fescue, slender creeping red fescue, sheep fescue, meadow fescue, and Kentucky bluegrass. Warm-season grasses include Bermuda grass, Uganda grass, Japanese grass, crabgrass, kikuyu grass, and saltgrass. There are some differences between cool-season and warm-season grasses, making it essential to identify and cultivate them accordingly. Various methods are used in grass formation, including spraying with water, vegetative propagation, seeding with soil cover, and ready-made grass molds[18,19]. The aim of this study is to convert and utilize significant amounts of grass waste generated in parks, gardens, and roadside areas into biogas energy. The chemical properties of grass waste (crude protein, crude fat, dry matter, ADF, and NDF), biogas, and methane yields (m^3/kg ODM) will be experimentally determined. Additionally, the total biogas energy production from grass waste has been calculated for a specific region taken as an example.

Expected outputs:

1) Determine the chemical properties of grass waste from parks and gardens (crude protein, crude fat, dry matter, ADF, and NDF).

2) Experimentally demonstrate the biogas and methane yields of grass waste from parks and gardens (m^3/kg ODM).

3) Determine the potential biogas energy values from grass waste for a specific region taken as an example.

4) Highlight the contribution of using organic waste for energy purposes to the economy.

2 Material and methods

2.1 Grass and grass silage materials

In the research, grass waste was collected from three different areas in the parks and gardens of Malatya in July. For each of the grass wastes collected from three different areas, a portion was used to make silage. The other part was dried completely in the sun and then ground with an industrial-type mill (BarTech, Turkey) with a 1 mm-diameter sieve[20]. For the weighing of the raw material and the obtained materials, a Kern brand precision balance (Kern & Sohn gmbh, Germany) was used. For the determination of ash and organic matter contents, a Microtest brand muffle furnace (Microtest Turkey) was used. A Nüve brand drying oven (Nüve, Turkey) was used for determining moisture contents, a Velp UDK 139 brand protein device (VELP Scientific, USA) for protein content determination, an ANKOM XT10 brand fat device (ANKOM Technology, USA) for fat content determination, and an ANKOM NDF/ADF fiber analysis device (ANKOM Technology, USA) for NDF and ADF contents. The inoculum with a solids content of approximately 2 was taken from the mesophilic environment of the wastewater treatment plant at the Kahramanmaraş Water and Sewerage Administration (KASKI) and had a pH value of 6.8.

2.2 Hohenheim Batch Test (HBT) method

In the HBT method, the test is conducted in 100 mL glass syringes (Figure 1). Figure 1 shows the patented Hohenheim Batch Test syringe. The syringe consists of silicone grease, plunger, inoculum-substrate mix, clamp, graduated scale, glass syringe, and capillary extension (Figure 1).

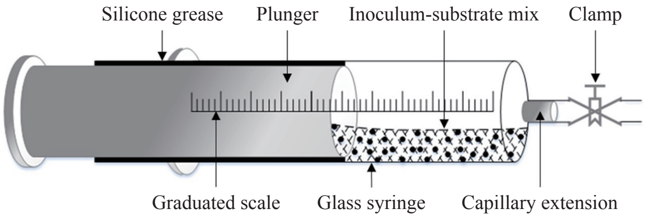

Figure 1 HBT syringe

The Hohenheim Batch Test syringes were placed in a hot water bath (Yapar Paslanmaz A.ş, Turkey) with 128 compartments, each equipped with a heater to heat the water inside (Figure 2).

Figure 2 Incubator

An infrared-spectrometric methane sensor, specifically the “Advanced Gasmitter” D-AGM Plus 1010 device (Sensors, Germany) with a sensitivity of 20 mL, was utilized to determine the methane content in biogas.

2.3 Preparation of materials

Immediately after collecting grass waste from three different areas, silage was prepared by allowing each batch of grass waste to ferment for 21 days. Following silage preparation, all materials were dried and ground through a 1 mm-diameter sieve. Three samples were used for each material (Table 1). For the determination of methane potential, all samples were weighed at 0.2 g on a dry basis and placed in 100 mL test syringes in triplicate[21].

Table 1 Materials used for methane potential determination

Materials	Number of samples
Silage 1	3
Silage 2	3
Silage 3	3
Grass 1	3
Grass 2	3
Grass 3	3

The chemical properties of the materials, including dry matter content, raw ash, organic matter determination, crude protein (Kjeldahl method), crude fat content (Soxhlet extractor method) according to AOAC 1990[22], and ADF and NDF determination according to Van Soest et al. 1991[23], were determined at the Laboratory of Biosystems Engineering Department, Faculty of Agriculture, Kahramanmaraş Sütçü İmam University.

2.4 Data evaluation

Measurements conducted in triplicate were analyzed for mean and standard deviation values, statistical differences, and variance analyses. The results were interpreted in Tables 2 and 3, and Figures 3-5.

Table 2 Chemical properties of materials

Material	Protein/%	Fat/%	NDF/%	ADF/%	DM/%	OM/%
Silage 1	17.42±0.87^a	5.13±0.10^a	46.00±0.07^b	29.00±0.08^b	83.48±0.21^b	92.48±0.02^a
Silage 2	17.49±0.06^a	5.11±0.05^a	50.00±0.05^b	30.00±0.04^b	82.87±0.37^b	92.59±0.07^a
Silage 3	17.48±0.23^a	4.73±0.25^a	46.00±0.01^b	29.00±0.01^b	82.21±0.49^b	92.47±0.02^a
Grass 1	17.05±0.24^b	3.17±0.08^b	68.00±0.04^a	41.00±0.07^a	90.52±0.24^a	86.18±0.45^b
Grass 2	16.94±0.03^b	3.45±0.08^b	66.00±0.13^a	40.00±0.02^a	90.92±0.45^a	86.45±0.20^b
Grass 3	16.93±0.12^b	3.77±0.02^b	63.00±0.19^a	40.00±0.14^a	90.24±0.46^a	85.90±0.26^b

Note: Statistical comparisons revealed significant differences ($p \leq 0.05$) in protein, fat, ADF and NDF, dry matter (DM), and organic matter (OM) ratios for all materials.

Table 3 Average cumulative specific methane, biogas values, and methane ratios in biogas for materials

Materials	Methane				Biogas				Methane in Biogas
	Measurements			Avg.±Std	Measurements			Avg.±Std	
	1	2	3		1	2	3		
Silage 1	0.41	0.42	0.38	0.400±0.120^a	0.67	0.70	0.64	0.670±0.016^a	60.04^a
Silage 2	0.39	0.40	0.39	0.390±0.005^a	0.68	0.68	0.64	0.670±0.012^a	59.01^a
Silage 3	0.41	0.41	0.39	0.400±0.005^a	0.63	0.69	0.65	0.650±0.016^a	60.19^a
Grass 1	0.41	0.42	0.40	0.410±0.005^a	0.69	0.69	0.67	0.690±0.006^a	59.30^a
Grass 2	0.42	0.42	0.42	0.420±0.001^a	0.71	0.70	0.71	0.710±0.012^a	59.52^a
Grass 3	0.41	0.42	0.39	0.410±0.007^a	0.67	0.71	0.67	0.680±0.005^a	59.48^a

Note: In the statistical comparison conducted, there were no significant differences ($p \leq 0.05$) in the mean values of cumulative specific methane, biogas production, and methane ratio in biogas for all materials.

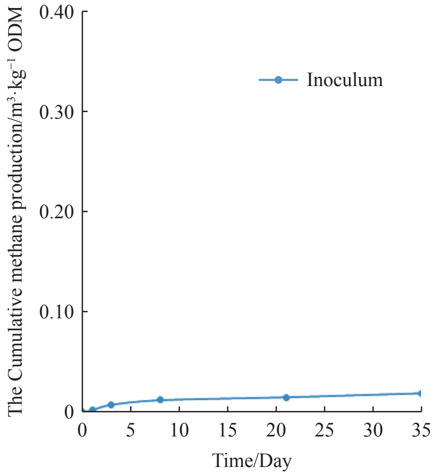

Figure 3 Inoculum cumulative methane production

3 Results and discussion

3.1 Chemical properties of materials

At the end of the study, the protein, fat, ADF and NDF, dry matter, and organic matter ratios of the materials were determined (Table 2). Protein, fat, ADF and NDF, dry matter (DM), and organic matter (OM) ratios varied between 16.93%-17.49%, 3.17%-5.13%, 46%-68%, 29%-41%, 82.21%-90.92%, and 85.90%-92.59%, respectively. Grass and grass silage showed differences in chemical composition. In silage, there was an increase in protein, fat, and OM ratios, while in grass, ADF, NDF, and DM ratios increased. The highest protein (17.49%), fat (5.13%), NDF (68%), ADF (41%), DM (90.92%), and OM (92.59%) ratios were observed in Grass 3, Silage 1, Grass 1, Grass 1, Grass 2, and Silage 2, respectively. The lowest protein (16.93%), fat (3.17%), NDF (46%), ADF (29%), DM (82.21%), and OM (85.90%) ratios were found in Silage 2, Grass 1, Silage 1-3, Silage 1-3, Silage 3, and Grass 3, respectively.

3.2 Material biogas and methane production values

In this experimental study, conducted under mesophilic conditions, the biogas and methane production of the inoculum and other materials were determined. Cumulative methane production graphs over time are given in Figures 4 and 5.

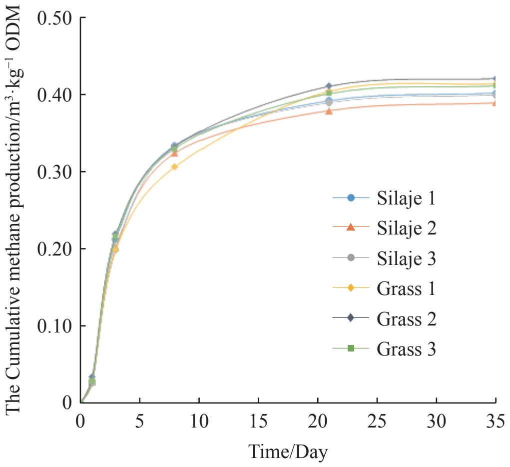

Figure 4 Examination of average methane production for all samples

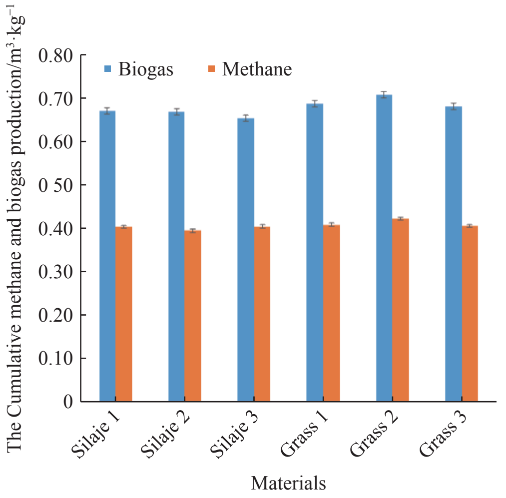

Figure 5 Change in average cumulative specific methane and biogas production of materials

3.3 Inoculum methane production

As a result of the measurements, the cumulative methane production of the inoculum after anaerobic (oxygen-free) degradation was approximately 0.02 m³/kg ODM (Figure 3). Inoculum gas production was subtracted for the net gas production of the materials. Inoculum gas production occurred between days 1-35 (Figure 3).

3.4 Examination of average methane production for all samples

In the study, the average cumulative specific methane productions over time for all materials (Silage 1, Silage 2, Silage 3, Grass 1, Grass 2, and Grass 3) are presented in Figure 4, while the average cumulative specific methane, biogas values, and methane ratios in biogas are listed in Table 3. The variation in average cumulative specific methane and biogas productions is illustrated in Figure 5.

The average cumulative methane production values for all materials ranged from 0.39 to 0.42 m^3/kg ODM. The highest cumulative methane production occurred in Grass 2 (0.42 m^3/kg ODM), while the lowest was in Silage 3 (0.39 m^3/kg ODM). The average cumulative biogas production values for all materials ranged from 0.65 to 0.71 m^3/kg ODM, with the highest cumulative biogas production in Grass 2 (0.71 m^3/kg ODM) and the lowest in Silage 2 (0.65 m^3/kg ODM) (Figure 4, Table 3, Figure 5). The methane ratios in biogas varied between 59.01% and 60.19%, with the maximum methane ratio in Silage 3 and the minimum in Silage 2 (Figure 4).

In the study conducted by Chiumenti et al. in 2018[24], they determined the methane and methane ratios in biogas for grass residues generated in spring and summer. In the research, methane production from grass cut in the spring was 0.31 m^3/kg ODM, while grass cut in the summer resulted in 0.34 m^3/kg ODM, and the maximum methane content in biogas was 55%. Mahnert et al.[25] investigated methane, biogas, and methane content in biogas from different types of grass using BMP (Biochemical Methane Potential) and semi-continuous system. In their study, biogas production values ranged from 0.65 to 0.86 m^3/kg ODM, methane production values ranged from 0.31 to 0.36 m^3/kg ODM, and methane content in biogas varied between 59% and 63%. Nizami et al.[26] conducted research on grass silage obtained by waiting for approximately 35 days after cutting the grass, and they investigated methane production and methane content in biogas using different methods. The study determined methane production values between 0.36 and 0.42 m^3/kg ODM and methane content in biogas as 54%. In this current study, the methane production values obtained fall within the same range as in Nizami et al.[26] but are higher than those reported in other studies.

Other biogas measurements for fresh cut grass were reported of 0.5-0.6 m^3/(kg VS) by Nizami and Murphy (2010)[27] and of 0.6 m^3/(kg VS) by Aboderheeba[28], and for grass silage of 0.54 m^3/(kg VS) by Czubaszek et al[29]and 0.56 m^3/(kg VS) by Heller et al.[30]. These differences may be attributed to variations in the cutting times of the grass, differences in chemical composition, seasonal variations, silage preparation, and inoculum characteristics.

Arıcı et al.[31] used the Biochemical Methane Potential (BMP) method to determine that grass waste can achieve a maximum methane yield of 397.7 mL/g of volatile solids (VS). This finding suggests that grass waste has promising potential as a biogas substrate, contributing significantly to renewable energy sources through anaerobic digestion processes. Mattioli et al.[32] reported a biogas yield of 0.659 m^3/kg of total volatile solids (TVS) for grass wastes using the BMP method. When compared with other studies, including Arıcı's, these results indicate minor variations in methane yield, likely due to differences in chemical composition, particle size, and waste type. These small discrepancies suggest that while grass waste is consistently a good substrate for biogas production, slight changes in its properties can influence the efficiency and yield.

4 Results

In this study, focused on the evaluation of grass residues, which have significant potential in Turkey and are periodically harvested during the summer months, the obtained results and recommendations are outlined below:

Chemical composition of materials:

The highest protein content (17.49%) was observed in Grass 3, while the lowest protein content (16.93%) occurred in Silage 2.

The highest fat content (5.13%) was in Silage 1, and the lowest fat content (3.17%) was found in Grass 1.

The highest NDF (Neutral Detergent Fiber) content (68%) was recorded in Grass 1, and the lowest NDF content (46%) was observed in Silage 1-3.

The highest ADF (Acid Detergent Fiber) content (41%) was in Grass 1, and the lowest ADF content (29%) was in Silage 1-3.

The highest dry matter (DM) content (90.92%) was in Grass 2, while the lowest DM content (82.21%) was in Silage 3.

The highest organic dry matter (ODM) content (92.59%) was in Silage 2, while the lowest ODM content (85.90%) was in Grass 3.

Methane production:

The average cumulative methane production values for all materials ranged from 0.39 to 0.42 m^3/kg ODM.

The highest cumulative methane production was in Grass 2 (0.42 m^3/kg ODM), while the lowest was in Silage 3 (0.39 m^3/kg ODM).

Biogas production:

The average cumulative biogas production values for all materials ranged from 0.65 to 0.71 m^3/kg ODM.

The highest cumulative biogas production was in Grass 2 (0.71 m^3/kg ODM), while the lowest was in Silage 2 (0.65 m^3/kg ODM).

Methane content in biogas:

Methane content in biogas varied between 59.01% and 60.19%, with the maximum in Silage 3 and the minimum in Silage 2.

No statistical difference was found in methane, biogas, and methane content in biogas among grass materials and silage.

Protein and fat: Both silage and grass had similar protein levels (around 17%), but silage had a higher fat content (4.73%-5.13% compared to 3.17%-3.77% for grass). This added fat content may contribute to energy density, though it can also require careful management to avoid microbial inhibition in the digester.

Fiber content (NDF and ADF): Grass had higher fiber content (NDF: 63%-68%, ADF: 40%-41%) compared to silage (NDF: 46%-50%, ADF: 29%-30%), which suggests that grass may be more resistant to rapid biodegradation. High fiber typically slows digestion rates but can yield stable, sustained methane over time when adequately processed.

5 Conclusions

The experimental results indicate that processing these wastes as either silage or in dried form for biogas production leads to no statistically significant differences in methane output, total biogas yield, or methane concentration within the biogas. This suggests that either storage method - silaging or drying - can be effectively used without impacting overall biogas or methane productivity. Thus, facilities can choose between silage and dried forms based on convenience, storage requirements, or cost, knowing that both methods will perform equivalently in biogas production. This flexibility provides valuable options for optimizing feedstock management and storage in biogas operations.

6 Recommendations

Grass residues generated during the summer can be utilized not only seasonally but also year-round by making silage from these residues for biogas production. Grass and grass silage materials can provide a consistent source for biogas production. Considering the current trend of establishing biogas plants for animal waste, mixing grass materials with animal waste can determine biogas and methane production values.

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