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ORIGINAL ARTICLE

A research on biogas production from a mixture of olive pomace and cattle manure

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Abstract

Energy has a strategic importance for all countries. To keep limited energy resources in proper use for a long time, the use of new energy and renewable energy resources should be expanded.

Significant amounts of organic residues are produced every year in agricultural areas and agro-industrial activities. Evaluating biomass resources and bringing them into the economy, they can be converted into useful energy in the area or region where they are formed. Turkey is one of the most important olive oil producers in the world, located in the Mediterranean Region. Olive pulp or pomace, as it is commonly known, produced in olive oil production is generally evaluated by burning.

In this study, biogas production amounts were determined by adding olive pomace in different proportions to cattle manure. The experiments were carried out in laboratory-type biogas reactors. The retention time was chosen as 15 days, the fermentation temperature was 37 °C, and the dry matter content was 7%. The experiments were carried out in 4 reactors as only cattle manure, 10% olive pomace + 90% cattle manure mixture, 25% olive pomace + 75% cattle manure mixture, and 40% olive pomace + 60% cattle manure mixture.

According to the experiment results, the highest daily methane production was obtained in the mixture with 40% olive pomace added. In methane production per organic dry matter, the mixture to which 25% olive pomace was added produced the highest methane.

Keywords Olive pomace · Biogas · Cattle manure · Co-fermentation · Anaerobic digestion

1 Introduction

The increase in the world population day by day, the development of technology, and the widespread use of products that will facilitate human life increase the energy consumption per capita in the world. This causes a compulsory increase in energy production in the world. This compulsory increase in energy production also brings environmental pollution because human beings still obtain most of the energy they need from fossil sources. In 2021, the world's total energy supply amounted to 624 EJ. The distribution of this according to sources is as follows: 5% from nuclear energy, 12% from renewable energy sources, 4% from traditional use of biomass, 23% from natural gas, 29% from oil, 26% derived from coal [1] (IEA, 2022).

Due to its ability to treat waste and recover energy, biogas is becoming one of the most popular renewable energy sources. Agricultural waste that cannot be used to animal feed is burned outside or allowed to rot. In this case, serious environmental and health problems occur. With biogas technology, both a clean energy and a good organic fertilizer for the soil can be obtained.

The fruit of the olive is an agricultural product that can be processed for oil and table use and the by-products of this processing can be evaluated. Because it is very beneficial for health, its demand is increasing all over the world. In the world, approximately 23.05 million tons of olives are produced on 10.33 million hectares of land. In Turkey, 1,738,680 tons of olives, which is approximately 7.55% of the world's total production, was produced [2]. Most of the olives produced in the world are used for oil production. The extraction of olive oil produces two streams: one is solid waste known as olive pomace, and the other, olive mill wastewater [3]. Olive pomace is a by-product of the olive oil production process and a very important biomass

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source for the Mediterranean countries. Olive pomace is a combination of olive husk and pulp, crushed olive stone, and olive mill wastewater with a moisture content of 65% [4, 5]. The main components of olive pomace are polysaccharides, proteins, fatty acids, polyalcohols, polyphenols, and other pigments [6] (Karantonis et al., 2008). The nature of solid and liquid residues produced in the olive oil production process depends on the technology used for the extraction of olive oil and the local conditions of operation [7–10]. For this reason, approximately 1 kg of olive oil is produced from 3 to 10 kg of olives. This value can be approximately 5 kg. In short, it can be accepted that 1 kg of olive oil and 4 kg of olive pomace are produced from 5 kg of olives. According to this calculation, olive pomace is at least 4 times more than the olive oil produced in the world. Olive pomace is abundant in the Mediterranean region. These wastes are left randomly in nature or burned directly. This causes environmental pollution.

In this study, in order to better utilize olive pomace, the amount of biogas that can be obtained from olive pomace and cattle manure mixtures was determined and compared with the amount of biogas obtained from cattle manure. Furhermore, this study is a study that can be put into practice. It is not just a study done in a laboratory environment to determine the potential of biogas. Many studies have been carried out as a batch system in glass tubes [11–15]. The biogas reactors used in this study are similar to real biogas plants. Besides, no chemicals were added to the substrate for pH regulation [16]. Olive pomace is produced in abundance during the olive oil production season and its storage creates great problems. In rural olive oil factories, olive pomace is used by burning, the easiest method. The investment costs are high to extract the pomace oil or to use it more beneficially and these local factories cannot make this investment. Also, there are not many studies on biogas production from olive pomace. More scientific experiments should be conducted on this subject for practical applications.

2 Materials and methods

The experiments were carried out in a specially built continuous flow–type laboratory reactor with a net fermentation volume of 5 L. A laboratory-type reactor unit consists of a fermentation chamber, a mixer, and a wet gas tank (gasometer) operating according to the fermentation channel principle. The schematic picture of the biogas reactor is shown in Fig. 1.

The reactor consists of two intertwined metal pipes. The inner tube is made of chrome nickel steel and the outer tube is made of steel. The mouths of the pipes are closed on both sides with round-shaped metal plates, making it

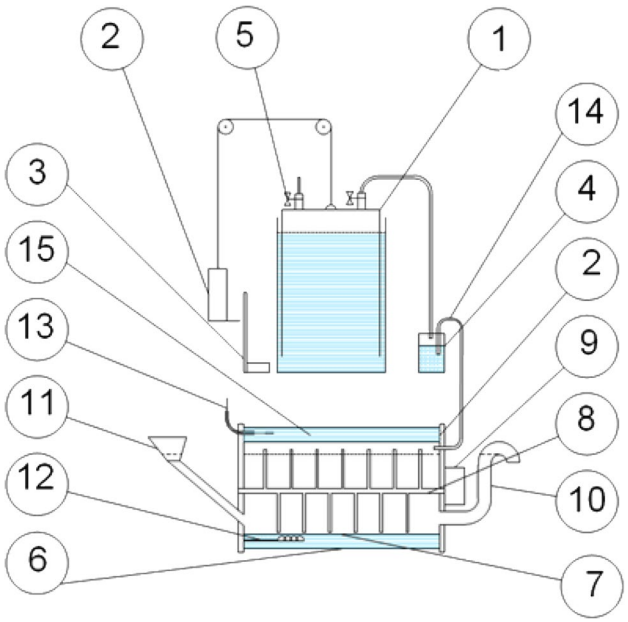


Fig. 1 Continuous-flow laboratory biogas reactor: 1, wet gasometer; 2, counterweight; 3, gas measurement scale; 4, pressure compensator (gas trap); 5, discharge valve; 6, outer pipe; 7, inner pipe; 8, mixer; 9, mixer motor reducer group; 10, discharging mouth; 11, loading mouth; 12, heating resistance; 13, temperature thermostat probe; 14, gas transmission pipe; 15, hot water pocket

a closed unit. These plates are connected to each other with shafts threaded at both ends. Both plates are made of steel material, and grooves suitable for pipe diameters are opened on their surfaces in order for the pipes to fit tightly. The fermentation chamber was formed with the pipe made of chrome nickel material. The space between the steel pipe and the chrome nickel pipe was filled with water and this formed the water pocket to be used for heating the material. To heat the water in the water pocket, an electric water heater was placed inside the water pocket. For temperature control, the heater was controlled by a digital thermostat.

A stirrer is needed to ensure that the material in the fermentation chamber does not settle. This agitator was realized by an electric motor on the reactor. The stirrer is made of thin sheet metal fingers connected to a chromium nickel shaft at an angle of 90°. The fermentation material was stirred for 3 min at 30 min^{-1} rotation every 27 min. A programmable timer was added to the system to adjust this time.

Loading and unloading of the reactor are done with the help of pipes attached to both sides of the reactor at a certain angle. While the amount calculated considering the retention time is loaded through the loading pipe, the appropriate amount of fermented material is taken out through the outlet pipe.

An empty volume of about 1.3 L left at the top of the fermentation chamber is reserved for the biogas to be

formed. It is planned that the biogas in this section will pass through the pressure equalizer via a transparent pipe and reach the gasometer where it will be stored daily. The amount of biogas produced was determined daily. To determine the amount of biogas produced daily, the amount of rise of the counterweights of the gasometers was determined. For this purpose, a simple device consisting of steel rulers was set up right next to the counterweights. The content of the biogas accumulated in the gasometer was determined every other day with a gas analyzer. To determine the content of the produced biogas, the Optima7 Biogas Analyzer produced by the MRU company was used.

The pH values of the substrate were measured both in the fresh material entering the reactor and in the fermented material leaving the reactor with a digital display pH meter. The amount of dry matter of the material was calculated with the help of weight reduction by keeping it in a drying cabinet at 105 °C for 24 h. The organic dry matter content was calculated from the remaining ash amount by burning in the incinerator at 550 °C [17]. In order to prevent the fresh manure from fermenting at room temperature, the prepared materials were stored at + 5 °C in a refrigerator with a glass lid.

In the experiments, the dry matter content of the fermentation material was tried to be approximately 7%. Since the organic materials (cattle manure and olive pomace) used in the trials were not completely homogenous, this value was tried to be approached in each new material preparation. The retention time in the experiment was chosen as 15 days. The fermentation temperature was kept at 37 °C. The heaters in the water pockets were adjusted to 37 °C with digital automatic thermostats. According to these values, approximately 333.3 g of fermentation material was loaded into the reactors every day.

Four reactors were used in the experiments. The first reactor was used as a control to determine the amount of biogas produced by cattle manure with only 7% dry matter content. Olive pomace was added to the cattle manure at 3 different rates. In the second reactor, 10% olive pomace mixture on dry matter basis, in the third reactor 25%, and in the fourth reactor 40% olive pomace were added to the cattle manure. The experimental plan is summarized in Table 1.

Cattle manure to be used in the experiments was obtained from Akdeniz University Animal Husbandry Facility. Cows are grown as dairy cattle in the facility. The fresh cattle manure was diluted with tap water (pH = 7) to 7% dry matter content and placed in the cooler in storage containers. The olive pomace used was obtained from an olive oil pressing plant located in the Antalya Gebiz neighborhood. The olive pomace obtained from the cold pressing plant filled 10-L plastic bottles, placed in the cooler, and kept at + 5 °C. Properties of olive pomace and cattle manure used in this study are shown in Table 2.

3 Results

The biogas reactors were fully loaded with cattle manure with a dry matter content of approximately 7% before the experiment and waited at fermentation temperature for 10 days without loading to increase the population of methane bacteria. During this period, the reactors were stirred, and the water pockets were heated. Only fresh material was not loaded. At the end of these 10 days, the reactors started to be regularly loaded with fermentation materials of the content foreseen in the experimental plan. When methane gas production started, the laboratory where the experimental setup was located was visited at 10.00 a.m. for 51 days to determine the amount of gas production, to load fresh material, and to measure the pH of the incoming and outgoing materials. The content of the biogas stored in the gasometers was determined using a biogas analyzer every other day. Dry matter and organic dry matter contents of the materials loaded into the reactors were determined. The reactors used in the experiment and the platform on which the reactors were placed are shown in Fig. 2.

Table 2 Properties of olive pomace and cattle manure

Material	Total solid (%)	Organic total solid (%)	pH
Olive pomace	29.61	95.383	5.01
Cattle manure	17.291	79.895	7.38

Table 1 The experimental plan

Material	Reactor no	Retention time (day)	Amount of material loaded per day (g/day)	Loading rate (g dry matter/L day)
Only cattle manure	1	15	333.3	23.3
%10 olive pomace addition	2	15	333.3	23.3
%25 olive pomace addition	3	15	333.3	23.3
%40 olive pomace addition	4	15	333.3	23.3

3.1 Biogas production (L/day)

Daily produced biogas in the reactors goes to the wet gasometer through transparent hoses. The biogas produced daily fills the gasometer and the small bucket rises in the large bucket. The amount of rise was read every day by means of scales. Each 2-cm rise of the gasometer was set to be 1 L. The readings were made by means of steel rulers glued on the scales. Measurements were made daily at the same time every day and recorded. The average of daily biogas production is given in Table 3. Extreme values were not included in the averages.

3.2 Biogas composition (%)

"Optima 7 Biogas" gas analyzer manufactured by MRU company was used to determine the composition of the biogas produced. This device has sensors working with infrared radiation detection method. The measuring device detected the oxygen, methane, carbon dioxide, and nitrogen gases in the biogas content as a percentage and hydrogen sulfide gas as ppm and recorded them on the memory card. Biogases collected in gasometers were analyzed every other day. Gas contents were determined by drawing the biogases collected in the gasometers with a vacuum pump on the device. In the measurement of the biogas in each gasometer, at least 3 data were taken and averaged. While the data were taken, the data were recorded by pressing the record button when the digital display was fixed.

When we look at the methane content of all experimental materials, the highest methane content was obtained from the mixture containing 40% olive pomace. This was followed by the material containing 25% olive pomace, the material containing all cattle manure, and the material containing 10% olive pomace. The table showing the biogas content of all materials is shown in Table 4.

As can be seen from the table, there is no significant change in the methane content of the biogas produced. Since the methane content of the biogas is above 50%, it has not lost its flammability. It was determined that the addition of olive pomace caused a decrease in the methane content of about 1 percentage point in the 10% mixture but increased the methane content by about 2 percentage points in the 25% mixture and by about 2.5 percentage points in the 40% mixture.

3.3 Daily methane production (L·CH_4/day)

The amount of methane produced per day (L·CH_4/day) was determined by multiplying the amounts of biogases produced per day by the methane ratios they contain. Daily produced methane amounts are given in Table 5.

3.4 pH changes

It is important to monitor pH changes in methane fermentation. It is understood from these changes whether the reactions occurring in the biogas production process affect the methane gas production. As the methane gas ratio in the biogas composition increases, its heating value and flammability increase. For example, if the pH of the substrate starts to decrease and the decrease continues, first the methane ratio of the biogas decreases and the carbon dioxide ratio increases. In short, its flammability is lost. Then



Fig. 2 Biogas reactors on the platfom. Research findings were analysed in six main groups: biogas production quantities, biogas contents, daily methane production, pH changes, reactor methane yield, raw material methane yield

Table 4 Biogas composition of experiment materials

Experiment materials	Gas type				
	CO_2 (%)	CH_4 (%)	N_2 (%)	O_2 (%)	H_2S (ppm)
Cattle manure	35.721	60.206	3.961	0.126	34.192
10% O.P. added	34.956	59.224	5.695	0.115	59.283
25% O.P. added	34.090	62.270	3.584	0.073	44.153
40% O.P. added	33.904	62.671	3.290	0.141	50.997

O.P., olive pomace

Table 3 Average daily biogas production (L/day)

Material	Cattle manure	10% olive pomace added	25% olive pomace added	40% olive pomace added
Average daily biogas production (L/day)	4.26596	4.75875	4.90784	5.00098

the amount of biogas production decreases and becomes zero and fermentation does not occur. It is desirable that the pH values of the substrates be around 6–7 when entering the reactors. In methane fermentation, organic wastes with these values are easier to process by methane bacteria. Sometimes pH-raising chemicals are used to treat low-pH organic wastes. The pH value of the olive pomace used in the trial materials was determined as 5.01 and the pH value of the tap water used for dilution was determined as 7.0. Although the pH value of the olive pomace is low, the pH value of the mixture remained within the ideal values when it was put into the fertilizer mixture. The pH values of the initial mixtures are shown in Fig. 3 and the pH values of effluent materials are seen in Fig. 4.

3.5 Reactor methane yield (L·CH_4/L·day)

Reactor methane yield is the amount of methane produced per unit time (1 day) from unit reactor volume. It is calculated by dividing the amount of methane produced in the reactor by the reactor volume. Reactor methane yields are shown in Table 6. While calculating the averages, the first 4 days of data for the mixture containing all cattle manure and the first 11 days of data for the mixture containing 10% olive pomace were excluded.

When we look at the experiment results, it was determined that the highest reactor methane yield was obtained from the mixture containing 40% olive pomace and 60% cattle manure. After this mixture, the reactor methane yield was

Table 5 Daily methane production (average)

Material	Cattle manure	10% olive pomace added	25% olive pomace added	40% olive pomace added
Average daily methane production (L·CH_4/day)	2.5733	2.8940	3.0550	3.1388

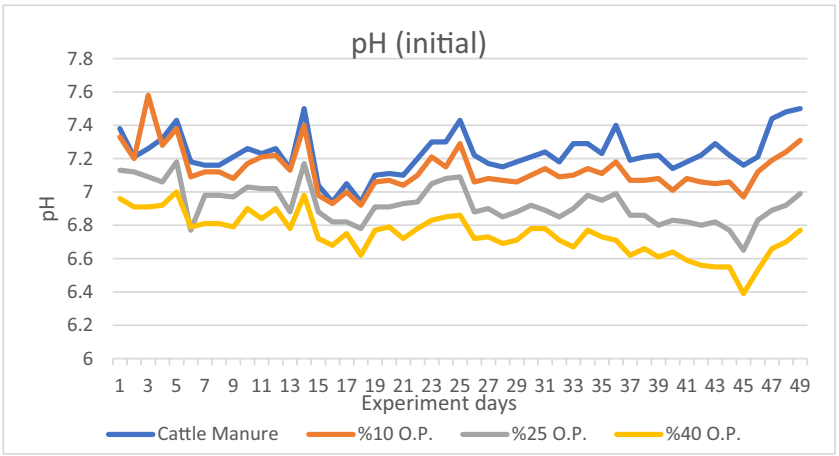


Fig. 3 The pH values of the initial mixtures

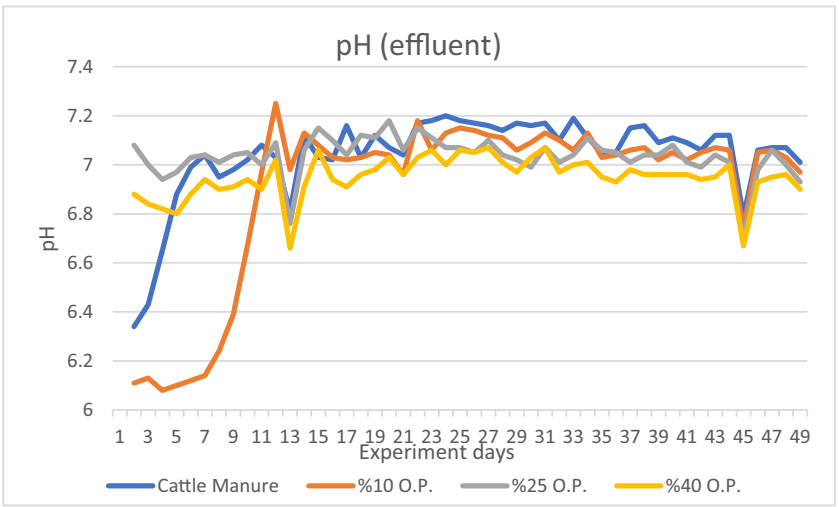


Fig. 4 The pH values of effluent materials

Table 6 Reactor methane yield (average)

Material	Cattle manure	10% olive pomace added	25% olive pomace added	40% olive pomace added
Average reactor methane yield ($L{\cdot}CH_4$/L·day)	0.515	0.579	0.611	0.628

followed by mixtures containing 25% olive pomace + 75% cattle manure, 10% olive pomace + 90% cattle manure, and cattle manure, respectively.

3.6 Raw material methane yield ($L{\cdot}CH_4$/g·ts·day, $L{\cdot}CH_4$/g·ots·day)

Raw material methane yield is the amount of methane produced per unit time (per day) from a unit weight of solids. Raw material yield was calculated by dividing the amount of methane produced per day by the amount of solids loaded per day.

The experiments were carried out in reactors with a fermentation volume of 5 L and the retention time was 15 days. Accordingly, 333.33 g of fermentation material was loaded into each reactor daily. The solids content of the fermentation material to be used was accepted as 7%. Accordingly, 23.33 g of solid material was loaded into each reactor daily. However, since both manure and olive pomace do not have a homogeneous structure, the solid content was tried to be adjusted to 7% solid content. According to the solid matter analyses made by keeping at 105 °C for 24 h, the average solid matter content of the cattle manure mixture used in the trials was determined as 6.9183% and the solid matter content of the olive pomace was determined as 7.1431%. After incineration at 550 °C, the organic solids ratio of the solid matter of the manure was 79.89% and the organic solids ratio of the solid matter of the olive pomace was 95.38%. Dairy cattle manure used in the experiments was diluted with tap water to have 7% solids content and mixtures to be used for about 10 days were prepared and stored in the cooler. Olive pomace was kept in 10-L plastic bottles and daily mixtures were prepared. Since the shells of the crushed olive pits in the olive pomace were heavier than the other parts, it was observed that they precipitated very quickly in the pomace and the upper part of the bottle was separated from the olive black water and the pomace. For this reason, the bottles were tried to be homogenized by shaking every day. The prepared 7% cattle manure mixture was mixed before each loading to homogenize the manure. Raw material methane yield values obtained during the experiment are given in Table 7.

4 Discussion

The aim of this study is to determine the usability of olive pomace in biogas facilities so that it can be evaluated in a more beneficial and environmentally friendly way. Turkey is a country that has a say in olive oil production. Agricultural statistics show that the number of olive trees, harvested olives, olive oil yield, and amount have increased over the years all over the world. For this reason, the amount of olive pomace obtained after the oil is extracted has been increasing over the years. Pomace oil is also obtained from the said pulp. However, in order to extract this oil, it is necessary to make a separate investment or to transport the olive pulp to the enterprises that extract this oil. In general, these facilities are not available in olive oil–squeezing enterprises and the pulp is used by drying and burning. The released olive black water is a separate problem. The olive pomace in question is disposed of by burning arbitrarily or throwing it into the nature, and some of it is processed in pomace factories. In this study, it has been determined that olive pomace can be used to obtain both energy and fertilizer.

In this study, the addition of olive pulp to cattle manure increased both the biogas production and the amount of methane produced. In addition, both the reactor methane yield and the raw material methane yield on the basis of solids and organic solids increased. No chemicals were

Table 7 Raw material methane yields

Material	Cattle manure	10% olive pomace added	25% olive pomace added	40% olive pomace added
Average raw material methane yields ($L{\cdot}CH_4$/g·ts·day)	0.112	0.125	0.131	0.134
Average raw material methane yields ($L{\cdot}CH_4$/g·ots ·day)	0.1397	0.1535	0.1567	0.1510

ts, total solid; *ots*, organic total solid

added to the reactor during methane production. When we look at such studies in the literature, there are few studies conducted with olive pomace. However, these studies are not directly related to the trials conducted here.

Tekin and Dalgıç (2000) conducted experiments with daily loading at 37 °C using only olive pulp in their study in Turkey [11]. The experiments were carried out in glass bottles with a volume of 1 L. Trials were carried out at 10% solids content, at 10-, 20-, 30-, and 40-day retention times. According to the test results, the highest methane production was determined as 0.550 L/day in the 20-day waiting period.

Rashed (2014) conducted an experiment using only olive pomace at 20, 40, and 60 °C temperatures in his study [12]. Fermentation was carried out in glass bottles of 1-L volume with a waiting time of 20 days. First, 300 g of olive pomace was diluted with water at a ratio of 1/1 and tested at three different temperatures, and it was determined that the optimum temperature for this mixture was 40 °C. In another experiment, the mixture obtained by mixing 180 g of olive pomace with 120 g of poultry manure and 300 g of water was fermented at three different temperatures. According to the results of this experiment, the highest biogas production was realized at 60 °C.

Ulukardeşler et al. (2016) investigated biogas production by mixing olive pomace, wastewater (black water), and different types of fertilizers (cattle, sheep, and quail) formed in the olive oil production process [13]. The experiments were carried out as a batch system in glass bottles with a volume of 3 L, at temperatures of 35–37 °C, and data were collected for approximately 42 days. The highest biogas production was obtained from a mixture of 150 g of olive pomace, 200 mL of olive oil production process wastewater, 150 g of cattle manure, and 2000 mL of water. However, no information was given about the methane content of the produced biogas.

Valenti et al. (2018) used six different vegetable wastes (citrus pulp, olive pomace, cattle manure, poultry litter, whey and corn silage) in their experiment in Italy [14]. These wastes were mixed in 6 different ratios, and the obtained mixtures were left to ferment in 500-mL glass bottles as a batch system at 35 °C. The batch anaerobic co-digestion demonstrated that six studied feedstock mixtures generated an average of 239 mL CH4/g VS loading without significant difference between each other. The highest olive pulp ratio in the mixtures is 29% dry matter. In this study, the effect of olive pomace on methane production could not be clearly seen.

Riggio et al. (2015) used cattle manure, olive pomace, and apple pulp as materials in their study [15]. The experiments were carried out in a pilot plant with a volume of 128 L, at 35 °C temperature conditions, as a batch system, during a 40-day waiting period. In the experiment, the amounts of biogas produced from 4 different mixtures were compared. The first mix is 85% cattle manure, 10% olive pomace, 5% apple pulp; The second mixture is 75% cattle manure, 15% olive pomace, 10% apple pulp; The third mixture is 65% cattle manure, 20% olive pomace, 15% apple pulp; The fourth mixture was composed of 70% cattle manure, 20% olive pomace, 10% apple pulp. According to the test results, the highest methane yield was determined as 216.3 L·CH_4/kg·ots from the first mixture (85% cattle manure, 10% olive pomace, 5% apple pulp).

In their study, Elalami et al. (2020) investigated the effects of alkali application, microwave application, and soundwave application on methane production [16]. The processes of adding only different amounts of NaOH to the olive pomace, microwave applications only at different times and strengths, microwave application with NaOH, and soundwave application with NaOH were compared. Among these applications, it was determined that the alkali application using only NaOH (8%) increased the methane production 30% more than all other applications.

Tufaner (2020) investigated the biogas production of olive pomace wastes in an upstream sludge bed anaerobic reactor [18]. The reactor with semi-continuous feeding was operated under mesophilic conditions (37 ± 0.5 °C) with a 10-day retention time. The substrate was prepared by diluting 52 g of crude olive pomace with tap water. An anaerobic reactor with an active volume of 6.15 L was used in the laboratory-scale study. In the study, the reactor was operated with an organic loading rate of 5.61 kg COD/m^3/day for 21 days. The pH value of the material was increased to 7.2 with NaOH solution and loaded into the reactor. As a result of the study, 1433 ± 436 mL/day biogas production was realized from the olive pomace. The CH_4 and CO_2 ratio of biogas was determined as 62.6% ± 4.1% and 27.7 ± 7.3%, respectively.

Amirante et al. (2018) investigated the effect of soundwaves applied to olive pomace in biogas production from olive pomace [19]. Biogas production was monitored daily for 43 days. According to the results of the experiment, after the first 10 days, biogas production from olive pomace not treated with soundwaves almost came to a standstill, while biogas production in the samples treated with soundwaves continued to increase in the following days. During the whole duration of the experiment, the production rate of the soundwaves-treated pomace samples was consistently higher than that of the non-soundwaves–treated ones. This result indicated that olive pomace is produced more rapidly and in greater quantities of biogas when preconditioned with an ultrasound pretreatment.

Batista et al. (2013) used olive pomace, olive oil mill wastewater, and whey mixtures as fermentation materials in their experiment in Puglia region, Italy [20]. Experiments were carried out in a 45-L continuous stirred tank reactor at 38 °C and 30–40-day retention time. The highest biogas production from these wastes mixed in different proportions

was obtained from a mixture of 25% olive pulp and 75% whey. Later, this mixture was fed to the anaerobic pilot plant with a volume of 1.6 m^3. As a result of this study, a 64% reduction in chemical oxygen demand (COD) and a daily biogas production of approximately 1.3 L/L were achieved. In conclusion, the authors determined that the use of these wastes obtained in the Puglia region can cover 0.015% of the annual total energy demand of this region.

In Orive et al. (2016), co-digestion of two-phase olive oil mill pomace and pig slurry at different ratios were studied in a semi-continuous stirred tank reactor at mesophilic temperature (37 °C) [21]. According to the result of the experiment, the best methane production occurred for a substrate composition of two-phase olive oil mill pomace/pig slury 80:20 w/w methane with production rates of 274.3 L CH4 kg VS^{-1}·day^{-1} at an organic loading rate 2.72 g VS·$Lreactor^{-1}$·day^{-1} and 24-day retention time.

5 Conclusion

As a result, the addition of 10%, 25%, and 40% olive pomace to cattle manure with 7% solids content caused an increase of approximately 11%, 15%, and 17%, respectively, in the amount of biogas production compared to cattle manure under 37 °C temperature conditions for 15-day retention time. If we compare the daily methane production amounts, the addition of 10%, 25%, and 40% olive pomace to cattle manure increased the daily methane production amount by approximately 12%, 18%, and 22%, respectively, compared to cattle manure.

If we look at the reactor methane yield, the result here is in parallel with the daily methane production amounts in terms of ratio. It was determined that the addition of 10%, 25%, and 40% olive pomace to cattle manure increased the reactor methane yield by approximately 12%, 18%, and 22%, respectively, compared to cattle manure. When the feedstock methane yield was analyzed on solids basis, the addition of 10%, 25%, and 40% olive pomace to cattle manure increased the methane yield by 12%, 17%, and 20%, respectively.

Finally, when the feedstock methane yield was compared on the basis of organic solids, the addition of 10%, 25%, and 40% olive pomace to cattle manure increased the methane production by 10%, 12%, and 8%, respectively. An important detail emerged here. When the amount of olive pomace was increased from 25 to 40%, the amount of methane produced per organic solids started to decrease. While the organic solids content of manure is 79.89% of the dry matter, this ratio is around 95.38% in olive pomace. Olive pomace contains a higher proportion of organic solids. The following conclusion can be drawn from this. Mixing olive pomace addition at a rate higher than 40% will start to reduce biogas and methane production. In order to prevent this, the use of NaOH to increase the pH level can be considered as an alternative solution.

The use of biogas technology is an alternative for the disposal of olive pomace wastes, which are abundant in Mediterranean countries, with more beneficial and environmentally friendly methods. The results of this study support this. It is a necessity for countries, which are dependent on foreign energy, to utilize their own resources in the best way possible, and to prevent pollution and protection of underground and surface resources for sustainable development. Biogas technology is an alternative for the most appropriate utilization of organic wastes.

Author contribution Not applicable.

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Data availability Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethical approval Not applicable.

Competing interests The author declares no competing interests.

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