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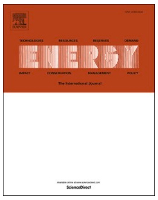

Waste-to-energy: Biogas potential of waste from coffee production and consumption

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ABSTRACT

The generation of waste is a necessary process related to the production and consumption of coffee. One of the wastes associated with the production of coffee is the husk, which separates from the beans when it is roasted. The waste from the consumption of coffee is spent coffee grounds generated during the coffee brewing process. The study aimed to determine the possibility of coffee production and consumption waste conversion in the anaerobic digestion process. The tested parameters were, among others, biogas efficiency, methane efficiency, and methane content in biogas. The experiment was conducted under anaerobic digestion conditions using DIN 38414/S8 norm. The total solids content of the coffee husk was 93.37%, with the organic matter content at 93.34%. The biogas efficiency in terms of fresh matter was 329.50 $m^3 \cdot Mg^{-1}$. The total solids content of all three analyzed grounds samples ranged from 41.27 to 45.72%. The high volatile solids content, in the 97.91–98.41% range, confirmed the biogas potential. In all three samples of coffee grounds, biogas efficiency was in the range of 225.45–270.97 $m^3 \cdot Mg^{-1}$. The obtained results allow concluding that analyzed coffee production and consumption waste have a high potential for biogas production.

1. Introduction

Coffee is a beverage made from coffee beans obtained from perennial and tropical plants. Beans are morphologically variable and have different shapes, colors, and sizes. Internally, seeds (usually two per fruit) are found, processed, and used to prepare infusions [1]. The most popular types of coffee are Arabica and Robusta [2], which are grown in regions stretching around the equator and the areas between the Tropic of Cancer and Capricorn [3]. The choice of the place of cultivation largely depends on the type of coffee and the climatic and soil requirements. The seeds are planted in shaded beds or containers filled with organically enriched soil. After sprouting, the seedling is replated into separate pots, and then, after reaching sufficient dimensions, it can be planted in the ground. The fruiting time for the coffee tree is about 20 years [4]. Unprocessed coffee beans are green and yellow-orange shortly before maturation. When they are ready for harvest, they turn bright red. The coffee fruit is divided into three layers: epicarp or skin, which is the outermost layer; mesocarp or pulp, which forms a sweet and aromatic pulp of mucilaginous nature, protected by a cellulose layer called parchment or endocarp; and finally, a silvery layer, which covers the two oval-shaped grains called endosperm. The leading coffee producers are in South American countries. The highest consumption occurs in Europe, although this beverage is drunk regularly worldwide [5].

The generation of waste is a necessary process related to the production and consumption of coffee [6]. The processing of the coffee beans causes the layers to be lost and to reach the beans. Only 5% of the bean is used to produce a coffee crop, and the rest remains in a residual form as husk leaves, branches, green fruits, pulp, mucilage, parchment, and silverskin. On the other hand, spent coffee grounds are waste generated during the coffee brewing process [7]. Spent coffee grounds contain lipids, carbohydrates, and nitrogen-containing compounds [8]. The increase in coffee consumption in the world is the reason for producing more and more waste and by-products. For each ton of coffee consumed, around 650 kg of residue is generated. In 2020–2021, world coffee consumption was almost 10 million tons, meaning about 6.5

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Abbreviations

FM	fresh matter
HRT	hydraulic retention time
MC	methane content [%]
TS	total solids [%]
VS	volatile solids [% TS]

million tons of coffee grounds were produced [9]. Analogously to other waste, spent coffee grounds should be managed according to the law [10].

The basic directions of waste management related to the production and consumption of coffee are their storage. Landfilling of biodegradable waste is not the preferred option and causes emissions that can harm the environment [11]. One of the most popular alternatives is using them for fertilization, e.g., in gardening. During the decomposition of the coffee grounds, humic substances are produced. These compounds are responsible for the development of the plant, its metabolism, and the hormone balance. Also, reducing the C:N from 26:1 to about 10:1. Adding coffee grounds to fertilizer can bind pesticide residues and toxic heavy metals, and use as mulch reduces soil temperature and increases soil moisture content. In addition, coffee grounds can serve as food for bio-consumers, such as earthworms, which aerate the soil and improve the nutritional supply of plants [12]. The use of coffee grounds for fertilization has a positive effect on the development of crops, however, it does not solve the problem of their emissivity.

Moreover, using them in this way does not fulfill their potential. A much better way is to use coffee grounds as additives, e.g., in cosmetics, food, and clothing products. Particularly noteworthy, in the context of the ongoing energy transformation, is the possibility of using coffee grounds to produce energy. Most of the waste associated with the production and consumption of coffee consists of an organic substance and are classified as biomass [13]. They can be transformed into thermal and biological processes. In the case of waste with a high total solids content, it is possible to use them to produce solid biofuels [14]. This group includes, among others, coffee husk [15]. Lignin, which in this process is responsible for binding structures in the biomass, accounts for approximately 33% of their volume [16]. It is also possible to burn them directly or blend them with other waste without prior processing. Another solution is the pyrolysis process. Among others, the possibility of processing coffee husk in the discussed process was examined by Dal-Bó et al. [17]. Waste containing more water should be dried before it is transferred to incineration processes. However, this generates additional costs.

Biological processing processes are an alternative to thermal processes [18]. This group includes composting and anaerobic digestion [19,20]. Composting of coffee waste has been widely discussed in the literature. Liu and Price [21] analyzed composting systems to manage spent coffee grounds. The conversion of spent coffee grounds into vermicompost was presented, among others, in research by Hanc et al. [22].

On the other hand, Sołowiej et al. [23] analyzed the effect of heat removal during the thermophilic phase on the energetic aspects of the biowaste composting process with the addition of spent coffee grounds. Considering the properties of waste and by-products related to the production of coffee and the growing energy demand, methods of energy use of the discussed substrates are becoming increasingly popular [24]. Apart from the products mentioned above of solid biofuels, including briquettes and pellets, attention should be paid to other processes [25]. For example, spent coffee grounds can be used to produce liquid biofuels. Coffee oil must be extracted to use coffee or waste related to its production. Among others, research on using spent coffee grounds for biodiesel production was presented by Caetano et al. [26]. On the other hand, the study by Kwon et al. [27] raised the issue of the co-production of biodiesel and bioethanol with spent coffee grounds.

The direction of using high and low-water-content waste is anaerobic digestion. As a result of the anaerobic digestion process, biogas is generated from substrates rich in an organic matter [28]. Its main component is methane. It should be emphasized that waste and by-products related to the production and consumption of coffee can be used to produce gaseous biofuels. Coffee grounds, mainly due to the content of compounds such as carbohydrates, proteins, or fats, are perfect as a substrate for a biogas plant. As previously mentioned, lipids, a component of coffee grounds, can significantly affect the amount of biogas produced. Due to the fragmentation, the discussed biomass does not require pre-treatment, which brings financial benefits and shortens the time it takes to prepare it for the process. It is also essential that the grounds can be easily separated from the rest of the waste immediately after the coffee brewing process. It means that such a substrate usually does not contain foreign materials, and thus the fermentation process itself is easier to monitor. In addition to the high content of lignin and other organic substances that positively affect the process, the grounds contain an appropriate C:N ratio, which was previously necessary when used as a fertilizer [29].

Another advantage of coffee grounds is the fact that despite the presence of potentially harmful compounds such as caffeine or polyphenols, they do not inhibit the process. The produced biogas is classified as a renewable energy source [30]. For this reason, the technology of methane production should be considered for many wastes from the agri-food and food sectors [31], especially in the context of systematically rising natural gas prices. Additionally, the digestate produced can be successfully used in fertilization [32]. It can allow reducing the demand for mineral fertilizers.

With the growing energy demand, alternative energy sources are required. Due to issues related to the circular economy, the preferred solution is to use waste and by-products for energy production. For this reason, research on waste related to coffee production and consumption was carried out. The study aimed to determine the possibility of coffee production and consumption waste conversion in the anaerobic digestion process. The tested parameters were, among others, biogas efficiency, methane efficiency, and methane concentration in biogas. According to the authors, the prepared article can fill some knowledge gaps and indicate further action directions.

2. Materials and methods

2.1. Materials

The substrate used for the research was the coffee husk obtained from the coffee bean processing company. Additionally, spent coffee grounds obtained from three cafes in Poznań (Poland) were used in the research. The substrates used in the research were analyzed to determine the basic physical and chemical parameters. Total solids were measured using the drying method (24 h at 105 °C) according to the Polish Standard PN-75 C-04616/01, volatile solids by burning dried samples at 525 °C for 3 h according to the Polish Standard PN-Z-15011-3, water solution (20 g in 200 ml of distilled water) according to the PN-90 C-04540/01 standard, and the conductivity according to the PN-EN 27888: 1999 standard. It should be emphasized that the measurement of total solids and volatile solids is necessary to conduct tests of samples' biogas efficiency according to DIN 38 414/S8 and to calculate the efficiency of biogas and methane production from 1 Mg of analyzed substrate mass. It has to be underlined that the Ecotechnologies Laboratory of the Poznań University of Life Sciences, as the 1st Polish biogas laboratory passed the "Proficiency Test Biogas" (test of the quality of biogas research efficiency analysis) organized by German organizations KTBL and VDLUFA in 2017.

2.2. Biogas production system

The experiment was conducted under mesophilic anaerobic digestion conditions (39 °C) in the 21-chamber fermenter set at the Ecotechnologies Laboratory of the Department of Biosystems Engineering at Poznań University of Life Sciences (Fig. 1). The biogas and methane efficiency were tested using German norm DIN 38414/S8. Anaerobic digestion experiments were carried out in the stirred tank reactors made of glass. The inoculum was the liquid fraction of digestate from one of the Polish agricultural biogas plants. The volume of biogas and its qualitative composition was checked using the GA5000 GeoTech company. A detailed methodology used for biogas production is described in the article by Cieślik et al. [33].

3. Results and discussion

3.1. Substrate characteristics

The total solids of coffee husk were 93.37%, and the content of volatile solids was 93.34% of the total solids. The total solid of the spent coffee grounds ranged from 41.27 to 45.72% for all three samples. Volatile solids for these three samples ranged from 97.91 for sample C to 98.42% for sample B. The pH for all analyzed substrates was similar and ranged from 5.23 to 5.48 (Table 1).

3.2. Methane fermentation tests

The decomposition time of the substrates in the fermentation reactor varies. This parameter depends on the substrates used to produce biogas, especially their properties and chemical composition. The anaerobic digestion process for coffee husk and spent coffee grounds was varied. Different dynamics of biogas production, including methane, are indicated, among others, as shown in Figs. 2-3A-C. The time for the decomposition of the coffee husk was 25 days, as shown in the figure showing one of the three replicates (Fig. 2). For spent coffee grounds, the scheduled time was shorter at 16 days. The decomposition was similar for all samples A, B, and C (Fig. 3A–C). The decomposition time of all analyzed substrates should be considered relatively short, mainly when the anaerobic digestion was carried out under mesophilic conditions. In the case of coffee husk, the maximum daily biogas production of over 0.5 dm^3 took place on the third and fourth day, and the methane production on the sixth and seventh days was less than 0.3 dm^3. In turn, spent coffee grounds were subject to a more dynamic decomposition. It increased biogas production as early as the third day and the highest proportion of methane in biogas on the eighth day (Figs. 2, Fig. 3A–C).

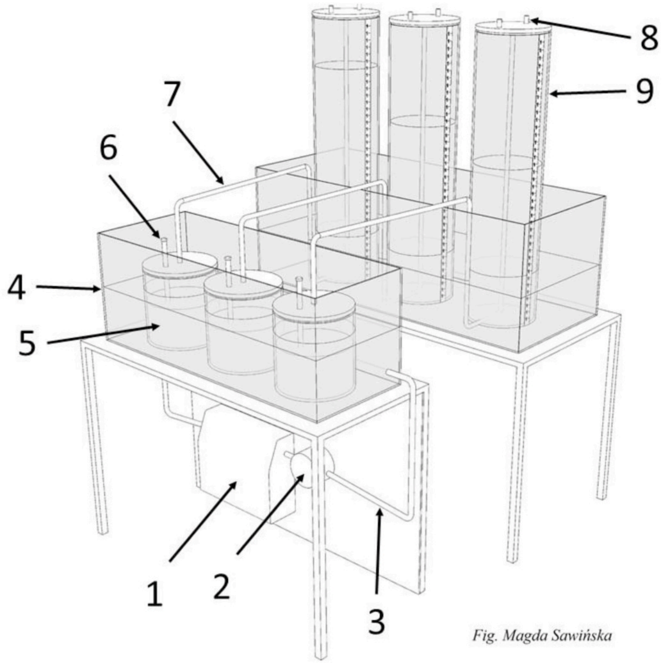

Fig. 1. The scheme of the biofermentor for the biogas production research 3-chamber section (1 – water heater with temperature regulator, 2 – water pump, 3 – insulated conductors of calefaction liquid, 4 – water coat with temp. 39 °C, 5 – biofermentor with charge capacity 2 dm^3, 6 – sampling tubes, 7 – biogas transporting tube, 8 – gas sampling valve, 9 – biogas volume-scale reservoir) [33].

Table 1
Selected parameters of analyzed substrates.

Sample	Initial parameters			
	pH	Conductivity [mS·cm^{-1}]	Total solids [% FM]	Volatile total solids [% TS]
Coffee husk	5.42	0.99	93.37	93.34
Spent coffee grounds A	5.48	1.09	41.27	98.41
Spent coffee grounds B	5.39	1.29	45.72	98.42
Spent coffee grounds C	5.23	2.00	44.37	97.91

As mentioned earlier, both the time of decomposition of raw materials and the daily production of methane and other gases varied for coffee husk and spent coffee grounds. On the other hand, the values for the three analyzed substrates of spent coffee grounds were relatively similar. Information on daily CH_4, CO_2, and H_2S production for coffee husk was presented in Table 2, and for spent coffee grounds in Table 3. The daily share of CH_4 in the coffee husk sample ranged from 38.9 to 76.1%. The lowest values occurred in the first days of decomposition under anaerobic conditions. The trend of increasing the CH_4 content was noticed from the beginning of the experiment, with a maximum value of 76.1% that occurred from day 18. With the increase of methane, the share of carbon dioxide in biogas decreased. It is confirmed by the data presented in Table 2. The highest value was observed at the beginning of the experiment, and it was 61.1%. Then the percentage share systematically decreased, reaching the lowest value of 23.9% on the 18th day, which depended on the CH_4 content. H_2S was tested in the sample, and its share was in the range of 19–250 ppm (Table 2).

The daily share of CH_4 in the sample of spent coffee grounds ranged from 35.5 to 79.8%. The lowest values were observed in the first four days of the experiment, with a minimum of 33.9% observed on the fourth day. The trend of increasing the CH_4 content was noticed from the beginning of the experiment, with a maximum value of 79.8% that occurred from day 11 and continued until the end of the experiment. As the share of methane increased, the share of carbon dioxide decreased. It is confirmed by the data presented in Table 3. The highest CO_2 value was observed in the first four days of the experiment. Then the percentage share systematically decreased, reaching the lowest value of 20.2% on the 11th day. The relation between CH_4 and CO_2 for spent coffee grounds was similar to the coffee husk. In the sample of spent coffee grounds, H_2S was tested. Its share was 6–94 ppm (Table 3), lower than for the second analyzed substrate – coffee husk.

The production of biogas and methane can be analyzed in two aspects. The first is the daily dynamics of the anaerobic digestion process and the amount of gas produced. The second aspect is biogas and methane efficiency per unit mass of substrates. Cumulative biogas and methane production for coffee husk and spent coffee grounds are presented in Table 4.

During anaerobic digestion in mesophilic conditions, coffee husk was characterized by the cumulative content of biogas per fresh matter at 329.50 $m^3 \cdot Mg^{-1}$. The methane efficiency of 173.59 $m^3 \cdot Mg^{-1}$ for the discussed substrate proves the average methane content at 52.68%. The cumulative biogas for the TS of the sample was 352.89 $m^3\ Mg^{-1}$ and

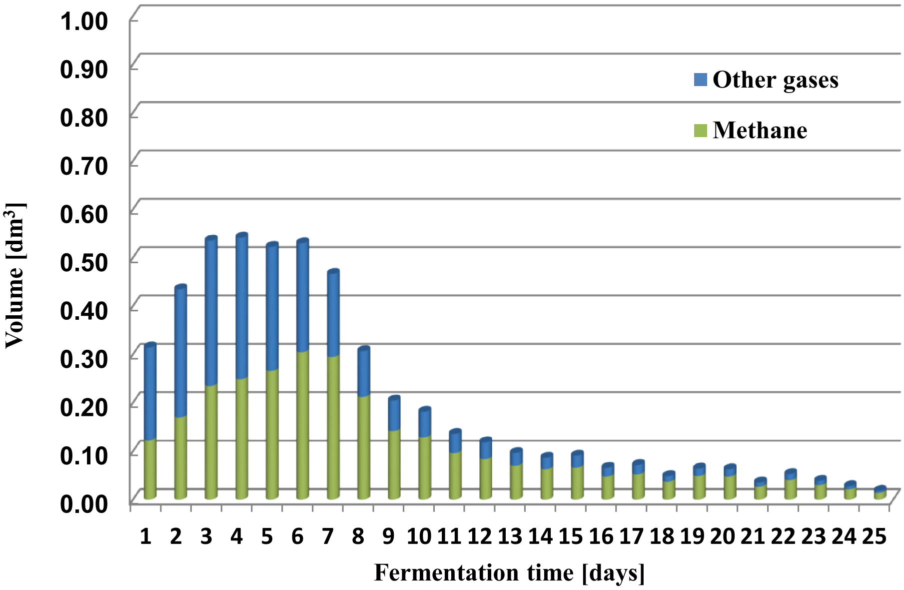

Fig. 2. Daily biogas and methane production for coffee husk.

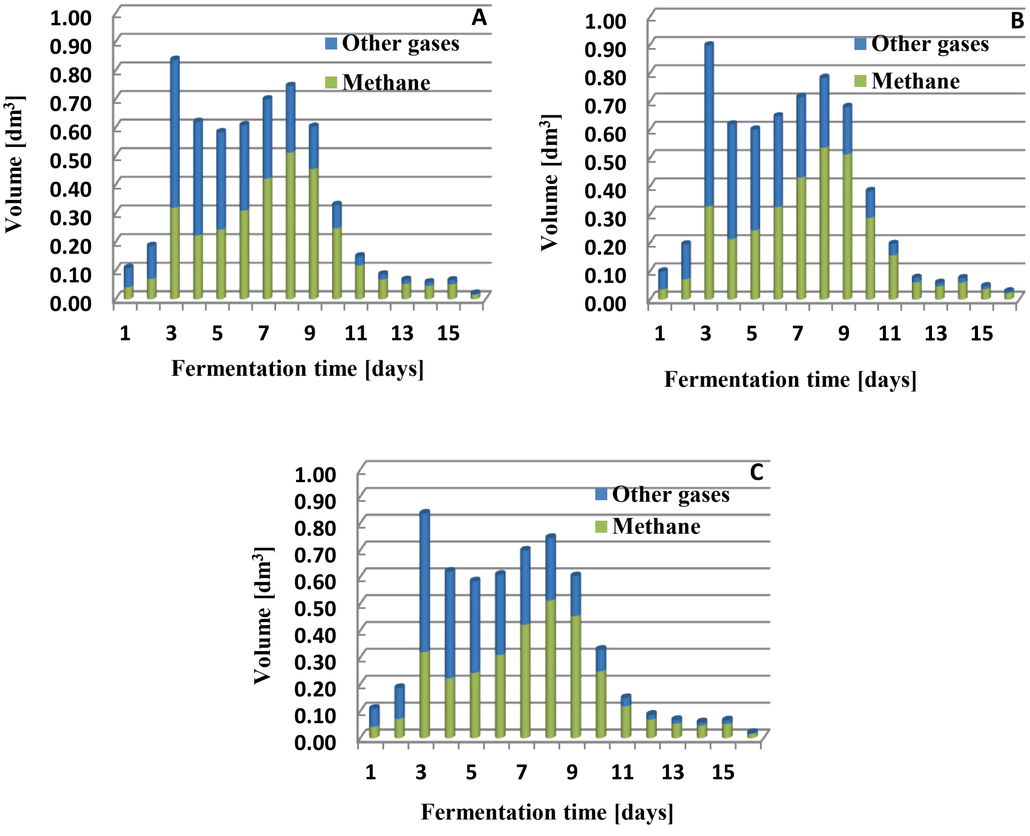

Fig. 3. A–C. Daily biogas and methane production for spent coffee grounds A-C.

378.08 m^3 Mg^{-1}, referring to VS. The three cumulative biogas values are similar due to the high TS content for coffee husk - 93.37% (Table 1). The cumulative biogas production for the three samples of spent coffee grounds was 225.45–270.97 m^3·Mg^{-1} in the fresh matter. The methane content was similar and amounted to 54.50%, 54.39%, and 53.85%, respectively, for samples A, B, and C.

The cumulative biogas results per TS for the three spent coffee grounds samples ranged from 546.28 to 592.68 m^3·Mg^{-1}. Referring to VS, it is from 555.12 to 602.18 m^3·Mg^{-1}. Analyzing both substrates in terms of cumulative biogas in terms of volatile solids, much higher values for the three samples spent coffee grounds should be found, with the maximum value of 602.18 m^3·Mg^{-1} for sample B (Table 2). The

Table 2
Daily CH_4, CO_2, and H_2S production for coffee husk.

Day	Volume [dm^3]	CO_2 [%]	CH_4 [%]	H_2S [ppm]
1	0.29	61.1	38.9	81
2	0.6	61.1	38.9	81
3	0.65	56.2	43.8	42
4	0.52	54.1	45.9	38
5	0.59	49.2	50.8	25
6	0.58	42.6	57.4	41
7	0.55	36.9	63.1	35
8	0.33	30.9	69.1	36
9	0.27	30.9	69.1	36
10	0.19	29.3	70.7	250
11	0.15	29.3	70.7	250
12	0.13	29.3	70.7	250
13	0.11	27.5	72.5	20
14	0.1	27.5	72.5	20
15	0.1	27.5	72.5	20
16	0.09	27.5	72.5	20
17	0.07	27.5	72.5	20
18	0.1	23.9	76.1	19
19	0.05	23.9	76.1	19
20	0.07	23.9	76.1	19
21	0.04	23.9	76.1	19
22	0.06	23.9	76.1	19
23	0.05	23.9	76.1	19
24	0.03	23.9	76.1	19
25	0.02	23.9	76.1	19

Table 3
Daily CH_4, CO_2, and H_2S production for spent coffee grounds C.

Day	Volume [dm^3]	CO_2 [%]	CH_4 [%]	H_2S [ppm]
1	0.12	64.5	35.5	44
2	0.29	64.5	35.5	44
3	1.07	64.5	35.5	44
4	0.67	66.1	33.9	19
5	0.66	59.4	40.6	10
6	0.81	49.5	50.5	94
7	0.75	39.3	60.7	41
8	0.79	31.2	68.8	14
9	0.86	24.4	75.6	11
10	0.35	24.4	75.6	11
11	0.21	20.2	79.8	6
12	0.06	20.2	79.8	6
13	0.08	20.2	79.8	6
14	0.1	20.2	79.8	6
15	0.02	20.2	79.8	6
16	0.03	20.2	79.8	6

lower biogas efficiency of coffee husk results mainly from lower volatile solids content and methane concentration.

An important parameter of substrates used in the anaerobic digestion process is their hydraulic retention time. From the point of view of the operation of a biogas plant, the most important is the fermentation period of approx. 90% of the total value – because the last 10% of the total fermentation potential is usually produced in the digestate tank. Hence, Fig. 4 shows the production time of 80%, 90%, and 100% of methane production in the anaerobic digestion process of the tested substrates. These results were compared with the dynamics of methane production in the case of maize silage digestion, the most popular substrate used in European biogas plants.

The obtained results indicate the good suitability of coffee grounds for anaerobic digestion due to the concise decomposition time (90% within 11 days). This is a much shorter period compared to maize silage. Conversely, coffee husk has a much longer decomposition time (90% in 17 days, 100% in 25 days). Nevertheless, this time is still relatively short compared to many biomass substrates containing lignocellulosic compounds. Therefore, it can be firmly stated that coffee waste, especially coffee grounds, is a very favorable substrate for use in biogas plants.

Waste is increasingly used to produce biogas instead of raw materials such as maize silage. This solution has many advantages, not only environmental but also economical. For this reason, coffee production and consumption waste are ideal for producing renewable energy. It was confirmed by both our research and research by other authors. Due to the availability of waste from the production and consumption of coffee, in recent years, many studies have been carried out on the possibility of using them for energy purposes, including biogas production. The results of the biogas efficiency of coffee husks were presented by Qiuxia et al. [34], where two tested samples reached the capacity of 244.8 $m^3 \cdot Mg^{-1}$ VS and 180.9 $m^3 \cdot Mg^{-1}$ VS. The results are higher than those obtained for mentioned samples A, B, and C; however, the fermentation time was almost 3 times longer and amounted to 60 and 68 days. Another research published by Ulsido et al. [35] estimated the efficiency at 131.67 + 5.75 $m^3 \cdot Mg^{-1}$ VS, which, in turn, is lower than that obtained in the conducted research. Similar results are also presented by Chala et al. [36] – 159 $m^3 \cdot Mg^{-1}$ VS. Additionally, it was found that the thermophilic condition can accelerate the anaerobic digestion process even to 20 days, which is half lower than the retention time required by the mesophilic condition. However, the quality of methane gas in the thermophilic condition is lower than in the mesophilic condition [37].

Similarly to husks, the efficiency of spent coffee grounds can be compared with the results published, among others, by Battista et al. [38], where the methane efficiency was estimated at 230 $m^3 \cdot Mg^{-1}$ VS. As the article's author noticed, the values are close to 293 and 310 $m^3 \cdot$

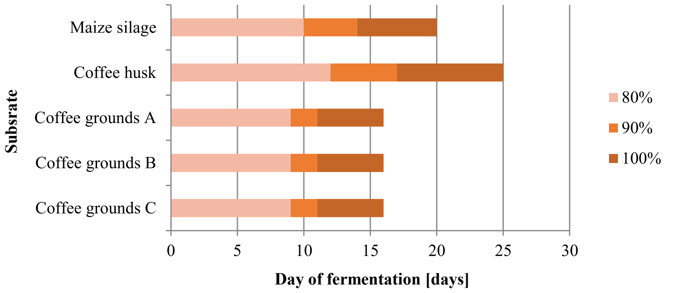

Fig. 4. Time required 80, 90, and 100% of total methane production from analyzed materials, compared with results of maize silage (the most popular substrate for a biogas plant in Europe).

Table 4
Cumulative biogas and methane production for analyzed substrates [FM – fresh matter, TS – total solids, VS – volatile solids, MC – methane content].

Sample	Methane content [%]	FM		TS		VS	
		Cumulative biogas [$m^3 \cdot Mg^{-1}$]	Cumulative methane [$m^3 \cdot Mg^{-1}$]	Cumulative biogas [$m^3 \cdot Mg^{-1}$]	Cumulative methane [$m^3 \cdot Mg^{-1}$]	Cumulative biogas [$m^3 \cdot Mg^{-1}$]	Cumulative methane [$m^3 \cdot Mg^{-1}$]
Coffee husk	52.68	329.50	173.59	352.89	185.92	378.08	199.19
Spent coffee grounds A	54.50	225.45	122.86	546.28	297.70	555.12	302.52
Spent coffee grounds B	54.39	270.97	147.38	592.68	322.35	602.18	327.52
Spent coffee grounds C	53.85	257.36	138.59	580.04	312.36	592.42	319.03

Mg^{-1} VS reported by Oliva et al. [39] and Atelge et al. [40]. In turn, Battista [41] published the result that amounted to 217 $m^3 \cdot Mg^{-1}$ VS. The research, which should also be mentioned, was published by Mahmoud et al. [42], where the methane efficiency totals 310–360 $m^3 \cdot Mg^{-1}$ VS.

Spent coffee grounds and husk were also reported as possible materials for co-digestion with multiple organic materials [43]. According to Kampioti and Komilis [44] and Mahmoud et al. [42], it can be mixed with an appropriate quantity of cow and pig manure, spent tea waste, food waste, or sewage sludge. Comparing the fermentation time and the amount of produced biogas, it can be concluded that coffee grounds are better suited for anaerobic digestion than coffee husks. Nevertheless, the test results for both products are satisfactory and qualify them as potential substrates for biogas plants.

Topics related to using waste for energy production are an essential area of scientific research. Due to the increase in the amount of biofuels produced in many countries worldwide, it is necessary to provide more and more substrates for their production [45]. The analyzed results showed that coffee waste is suitable for anaerobic digestion and typical agri-food industry waste, e.g., manure, vegetable, or fruit pomace. The appropriate content of total solids and volatile solids, as well as the C/N ratio, makes the yield of both husks and coffee grounds satisfactory. In none of the analyzed cases, the presence of inhibitors that could slow down or stop the process was found. In addition, the coffee grounds, due to the form they receive after brewing and consuming coffee, require virtually no pre-treatment. Due to the possibility of monofermentation or combining them with other substrates, the use of coffee waste depends primarily on its availability.

It should be emphasized that the issues related to the conversion of biomass resources into biofuels are becoming extremely important in the context of conflicts occurring in the world [46]. Currently, in Poland and many countries worldwide, biogas is converted into energy in the cogeneration process. However, an increase in biomethane production and its injection into the gas network should be expected soon [47]. In addition to anaerobic digestion, the second recommended method of processing coffee waste is to create solid fuels in the form of briquettes and pellets. Currently, several European companies are already engaged in such production and successfully sell their products. Chen and Chen researched the use of spent coffee grounds, chopsticks, and polypropylene spoons as a co-substrate in the pelleting process and then torrefaction. The highest heating value of the sample with 50% spent coffee grounds was 26.21 $MJ \cdot kg^{-1}$ [48]. Even though the process of anaerobic digestion of coffee waste in a laboratory was satisfactory, at the moment, there is no use of this method on an industrial scale. Regardless of the discussed substrates management, it is advisable to use sustainability assessment tools, including life cycle assessment [49].

4. Conclusions and further research directions

The production and consumption of coffee generate a significant amount of waste that should be rationally managed. It would help avoid or reduce the negative impact on the environment. One of the wastes associated with the production of coffee is the husk, which separates from the beans when it is roasted. The waste from the consumption of coffee is spent coffee grounds generated during the coffee brewing process. Due to their properties, both of the wastes mentioned can be used, among others, for fertilization and energy purposes. The coffee husk is commonly used to produce solid biofuels, and spent coffee grounds are considered waste. However, both of these wastes may be used for fertilization purposes. Due to the high content of total solids and volatile solids, these substrates can be used for energy production, including the production of not only solid but also gaseous biofuels. Spent coffee grounds, mainly due to the content of compounds such as carbohydrates, proteins, or fats, are a suitable substrate for biogas production. Like coffee husks, they contain much organic matter. Due to the fragmentation, the discussed waste does not require pre-treatment. It can allow for a better decomposition of the substances during anaerobic digestion. As an added benefit, there are no costs associated with fragmentation.

The challenge in managing waste and by-products related to the production and consumption of coffee is to develop a system for collecting spent coffee grounds. Due to the relatively small scale of production and large dispersion of waste generation places, the energy use of waste related to the production and consumption of coffee requires reasonable measures. It is crucial because waste production is highly dispersed, especially with coffee grounds. One solution may be collecting coffee grounds with other biowaste or food waste. It would allow obtaining a variety of feedstock for the biogas plant. Supply of various raw materials as fermentation input can guarantee the availability of various nutrients for the microorganisms involved in anaerobic digestion. Consequently, it would create better conditions for their development and biogas production. This action can also be beneficial in terms of economic and energy balance and increase the profitability of the discussed solution. Using waste such as coffee husk and spent coffee grounds is justified in energy, economics, and environmental aspects. The production of gaseous biofuels from the discussed waste is part of the activities related to sustainable development and the circular economy.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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