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Biogas production from waste food as an element of circular bioeconomy in the context of water protection

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ABSTRACT

Production of food use huge amounts of water. The loss of food leads to the waste of resources such as land, water and energy. Water protection and management of waste food are elements of a circular economy. Numerous studies have shown utilization of food for biogas production. However, much less attention is paid to use different source of waste food and biochar in anaerobic digestion. Utilization of waste food for production of energy career is the answer on societal, economy and environmental needs and helps to protect water. The aim of the research was to assess the possibility of using wasted cheese, spend coffee ground, dessert and rice and biochar for the production of biogas. The tests were carried out in glass reactors. The yield of biogas production was dependent on the chemical composition of a substrate used. Due to the high protein content in cheese, the high amount of biogas was produced (76.00%). Cheese with biochar achieved the highest yield of biogas production. Substrates that contained high amounts of sugar, such as rice and dessert, showed a lower biogas yield. Biochar that was added to the cheese induces an increase on the biogas production of 0.153 $Nm^3/kg·SV$, and an increase of methane production of 0.135 $Nm^3/kg·SV$.

Keywords: Waste food; Biogas production; Methane

1. Introduction

Production of food use huge amounts of water. The surface of the earth is composed of 70.8% water, of which only 2.5% is suitable for human consumption, therefore the waste of water should be avoided. Due to the increase of the population, agriculture and fishing will keep increasing, affecting the overexploitation of natural resources, especially water.

The circular economy can help to reduce resource consumption and contaminants emissions to the environment by changing from a linear and unsustainable system (take, make, consume and waste) to a circular. Water protection and management of waste food are elements of the circular economy [1]. Since one of the concepts of a circular economy is to keep product in use as long as possible, then utilization of waste food for production of energy career is the answer on societal, economy and environmental needs. Food is an element of bioeconomy therefore management of waste food is directly connected to circular bioeconomy.

In the land available for agriculture purposes, around 28% of the crops are wasted, the water that is used on those lands are approximately 250 km^3 according to the Food and Agriculture Organization (FAO) [2]. The utilization of water is essential for the production of biomass, for example, algal biomass that could be used as food that does not generate wastes [3].

Each year, approximately 1/3 of the food produced on the planet is lost or wasted. It mostly affects the increasing of the environmental pollution and water losses that was used for cultivation of plants. The effect that food waste has on the environment has a long background, since the

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pollution begins from the moment the food is being produced, due the high amount of natural resources that are used during the cultivation, transportation and packing of the food, in which some percentage of it will eventually end up as waste [2].

The loss of food leads to the waste of resources used in production such as land, water, energy and inputs, as well as producing an unnecessary emissions of CO_2, contributing to the global warming and climate change [4].

According to the EPA (Environmental Protection Agency) still most of the world's energy comes from the fossil fuels like natural gas, coal and oil [5]. Fossil fuels as non-renewable sources of energy represent a big role in the environmental pollution, beginning from the moment when the fossil fuels are extracted from the subsoil, all along until it is treated and burned in the process of obtaining energy [6].

The burning of fossil fuels has a negative impact on aquatic and terrestrial ecosystems and on human health [6]. Fossil fuels contribute to the production of several gases such as sulphur dioxide, nitrogen dioxide and volatile organic compounds, resulting in what is known as acid rain, smog, among others very dangerous substances for the environment [6].

Efforts should be made to obtain energy in a more environmentally friendly way. Recently, the production of energy from organic materials as substrates for the anaerobic digestion process has been of great interest [8].

Biogas produced by the fermentation of organic matter, through the process of anaerobic digestion is a mixture of mainly methane (CH_4), and carbon dioxide (CO_2), however, biogas also contains a small percentage of other chemical compounds [9]. The substrates that are suitable to carry out the process of anaerobic digestion in the biodigester have to be any type of raw material that is organic thus it decomposes, for example: wastewater sludge, residues of animal origin, residues of plant origin, agroindustry waste, blackwater [10,11].

Anaerobic digestion takes place in fermentation reactors, designed to maximize the methane yield of the different substrates [12].

Several studies have shown utilization of food for biogas production. However, much less attention is paid to use different source of waste food and biochar in anaerobic digestion [13,14]. The utilization of waste food for production of energy career is the answer on societal, economy and environmental needs.

The waste food has general characteristics that can be extrapolated all over the world. They have a moisture content of 74%–90%, a high percentage of volatile solids around 85% and an acid pH of about 5.1. Food waste is mainly composed of degradable carbohydrates (41%–62%), proteins (15%–25%) and lipids (13%–30%) [12].

Disposal of food waste directly to municipal landfills is a loss energy and water. The quantity of water in food waste utilized during the process of anaerobic digestion helps saving water and energy. Anaerobic digestion of food waste is a complex process that should simultaneously digest all organic substrates (such as carbohydrates and proteins) in a single-stage system. This process is governed by several key parameters such as temperature, VFA (volatile fatty acids), pH, ammonia, nutrients, trace elements and others [15,16].

The accumulation of the organic acids inhibits the phase of methanogenesis. As a consequence, a high inoculum to substrate ratio (ISR) is usually required to reduce the bio-stabilization time of solid organic waste or to avoid acidification [16].

The use of the biochar is effective in increasing digestion performance, because when the ISR decreases, the demand for biochar increases. Therefore, the effect of biochar as an additive for anaerobic digestion is to improve the function of the inoculum [17,18]. The addition of biochar during AD may also reduce substrate-induced inhibition (SII: substrate – induced inhibition) and increase process stability. Moreover, the application of biochar improves the quality of the digestate, contributing to the retention of nutrients and reducing their leaching [19].

An important by-product of anaerobic digestion is a digestate (or "digested mud"), liquid or solid material that remains at the end of the process. It contains nitrogen, phosphorus, potassium, calcium and other elements and should be management. It can be used, for example, as fertilizer and soil improver [20].

The use of biochar in anaerobic digestion has not yet been fully studied, but biochar certainly has a positive impact both on the stability of the process and on the quality of the digestate produced [18].

Biogas is usually used in boilers, to produce heat, as a fuel for vehicles in transport, in engines or turbines to generate electricity, purified is introduced in natural gas networks, or as a base material for the synthesis of methanol, a product of high value added [21].

The main aim of the presented research was to assess the possibility of using waste food for the production of biogas. The specific aims of the study are: to evaluate the amount of biogas production from the most common food waste: cheese, rice, dessert and spent coffee grounds (SCG) and to assess the effect of biochar on production of biogas from cheese.

2. Materials and methods

2.1. Substrates

The food was all expired products that were not suitable for human consumption any more. These foods have been selected from a list obtained from several sources which were put in a data base, showing the kind of food that is more likely to be throwed to waste. The foods that were used as substrates are shown on Fig. 1.

The cheese (Fig. 1a) used as a substrate to carry out the research, was a typical Italian cheese use in daily diet. The cheese was used after few days of its expiration date in order to avoid the acidification of the substrate.

The spent coffee (Fig. 1b) grounds are waste formed in espresso machine are a typical waste of a bar or coffee shops. Those used during the experiments were taken from a bar at the end of the day, before they were thrown into the organic bin.

The dessert (Fig. 1c) used during the test was taken at the end of the day from a bar. The dessert was about to be thrown away to the bin because it was not suitable for the human consumption anymore.

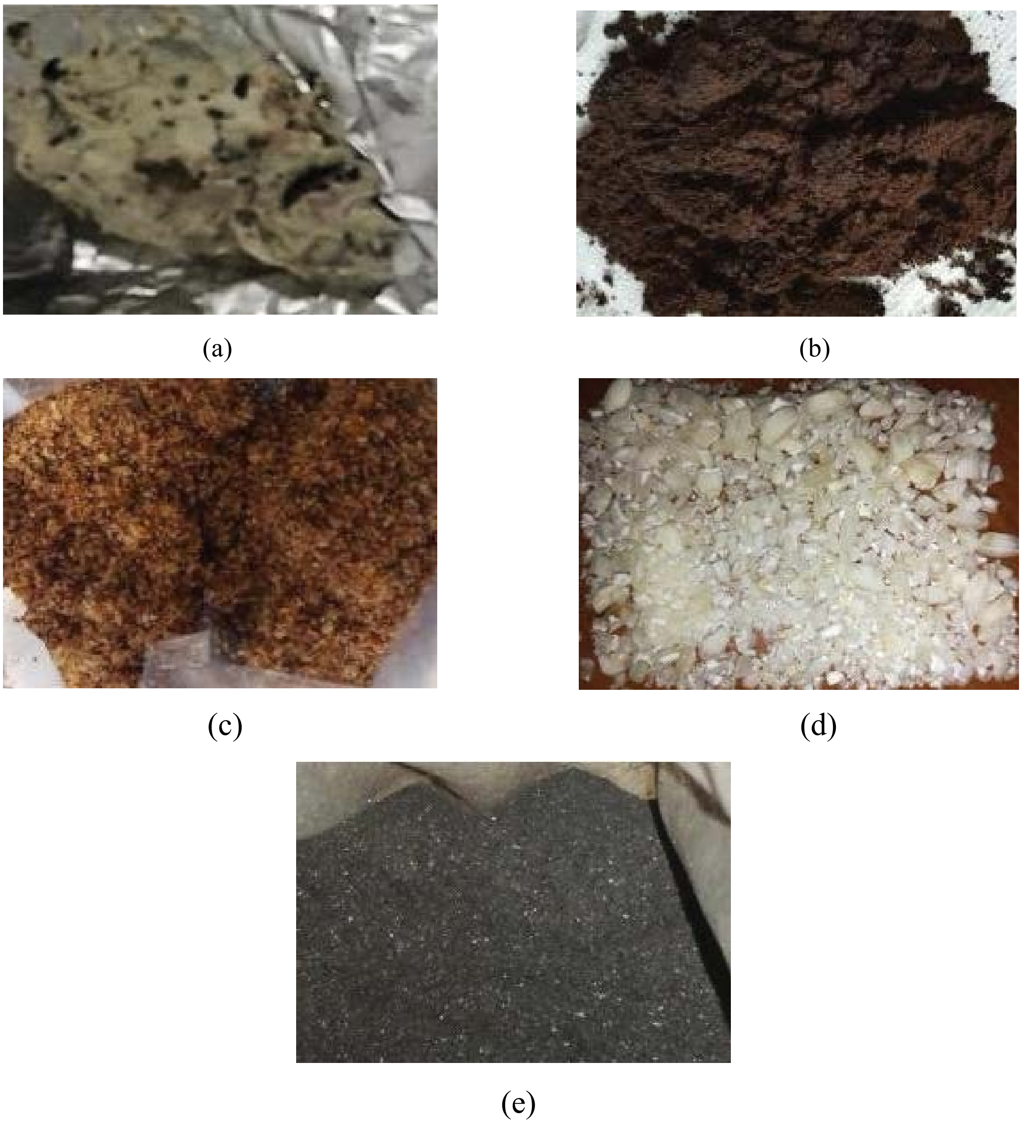

Fig. 1. Substrates used for biogas production.

The rice (Fig. 1d) used in the trial had exceeded the expiration date for about 30 d and, therefore, would be no longer suitable for human consumption. Rice was kept in a vacuum and therefore less susceptible to degradation phenomena.

The biochar (Fig. 1e) used during the testing is derived from a slow process of pyrolysis. Pyrolysis is a chemical decomposition of organic matter by heating at high temperatures in the absence of oxygen.

2.2. Set-up

The system that has been used in this research for the production of biogas was the batch system and experiments were conducted under anaerobic conditions at a maximum duration time of 37 d. The thermostatic bath was used. The batch system was loaded in the day 0, and the time of hydraulic retention is determined as a function of the temperature.

Table 1 shows the composition of the bottle 1B (cheese as a substrate), 2B (cheese with biochar as a substrate), 1C (dessert as a substrate), 2C and 3C (spent coffee ground as a substrate), 4B and 4B (rice as a substrate), with the respective weight and percentages.

2.3. Analytics

The biomethane potential (BMP) tests were carried out in borosilicate glass bottles made according to the standards defined by the UNI EN ISO 11734 standard of June 2004 [22].

For the characterization of the produced gas, the gas chromatograph Varian 490-GC.PRO Micro-GC was used. From the analysis with the gas chromatograph the percentage of methane present in the biogas was obtained and from this the methane yield expressed in $Nm^3/kg{\cdot}SV$ was calculated. In order to obtain the biogas and methane production in $Nm^3/kg{\cdot}SV$, Nm^3 (cumulative methane volume during the digestion time) was calculated first by multiplying the values obtained by 0.0224 Nm^3·mol (volume of one mole of ideal gas) and then dividing the result by the kg·SV (mass of substrate added to the reactor in terms of volatile solids) present in the mixtures. From the measurement of pressure using the ideal gas law equation: $pV = nRT$, the moles of biogas were obtained.

The thermogravimetric analysis in relation to the percentage of volatiles, ash and carbon in a wet base was done. The sensor for measuring the gas pressure produced consists of eight general transducers (Electrical mod. UNIK 5000). A mass spectrometer was used to assess CHN content. The pH measurement was carried out with the HI9124 portable pH meter equipped with a temperature detection probe and a pH detection. Each experiment was done in triplicates.

3. Results and discussion

3.1. Physico-chemical characterization of biomass

In order to determine the production of CH_4 of the substrates that are used for the production of biogas it could be used the biomethane potential (BMP) analysis [23]. The BMP test is carried out with a mixture of the substrate and the inoculum. The BMP is responsible for carrying out the following functions [24]:

- is the one that helps to determine the maximum production of CH_4 in the biogas at the same time as the anaerobic biodegradability produced,
- identifies the energy production potential of a substrate,
- develops indicators determining potential substrates,
- it is the one that identifies the inhibition or adaptation of microorganisms,
- simulates the digestion process and predicts the operation of digesters on a real scale [24,25].

Preliminary to the BMP tests, it was necessary to characterize the substrates by performing thermogravimetric analysis (TGA) and pH test in the substrates.

3.1.1. Thermogravimetric analysis (TGA) results analysis

Table 2 shows the results of the thermogravimetric analysis in relation to the percentage of volatiles, ash and carbon in a wet base, which plays an important role in the characterization of biomass.

The substrates possess different contents of volatile solids (VS), ash as well as humidity.

3.1.2. pH measurement results

Table 3 shows the results of the pH observed for the substrates: cheese, rice, dessert, spent coffee ground and biochar.

The highest pH was observed for biochar, add the lowest pH = 5.1 for dessert.

3.2. Production of biogas

The temperature to which the BMP tests were subjected, was under mesophilic condition (40°C).

The cumulated production of biogas and methane from the cheese is even respectively at 0.748 and 0.565 Nm^3/kg·SV, with a maximum percentage of equal methane about 76%. The trend of biogas and methane production is shown in Fig. 2.

Table 1
Content of the samples

Content of the individual samples	Quantity (%)	Weight (g)
Cheese	5.2	13.0
Inoculum	90.0	225.0
Deionized water	4.8	12.0
Total 1B	100.0	250.0
Cheese + biochar	5.2	13.0
Inoculum	90.0	225.0
Deionized water	4.8	12.0
Total 2B	100.0	250.0
Dessert	2.4	6.0
Inoculum	76.8	192.0
Water	20.8	52.0
Total 1C	100.0	250.0
Spent coffee grounds	6.0	15.0
Inoculum	84.0	210.0
Deionized water	10.0	25.0
Total 2C/3C	100.0	250.0
Rice	2.8	7.0
Inoculum	91.6	229.0
Deionized water	5.6	14.0
Total 3B/4B	100.0	250.0

Table 3
pH measurements

Parameter	Cheese	Biochar	SCG	Dessert	Rice	Inoculum
pH	6.4	7.9	6.0	5.1	6.1	7.7

Table 2
Thermogravimetric analysis (wet basis)

Content	Cheese (%)	Biochar (%)	SCG (%)	Dessert (%)	Rice (%)	Inoculum (%)
Volatile solids (VS)	37.3	23.0	32.2	69.6	71.7	7.2
Humidity (U)	60.4	5.5	62.0	15.7	10.1	90.1
Ash	1.0	11.0	0.4	1.9	0.9	1.7

The cumulative production of biogas and methane related to cheese with biochar is even respectively to 0.901 and 0.700 $Nm^3/kg{\cdot}SV$, with a maximum percentage of equal methane around 78%. The trend of biogas and methane production is shown in Fig. 3.

The cumulative production of biogas and methane related to the dessert is, respectively, equal to 0.747 and 0.527 $Nm^3/kg{\cdot}SV$, with a maximum percentage of methane equal to about 71% according to the following table the trend of biogas and methane production is presented in Fig. 4.

The cumulative production of biogas and methane related to spent coffee grounds appears to be even respectively at 0.598 and 0.377 $Nm^3/kg{\cdot}SV$, with a maximum percentage of equal methane at about 63%. The trend of biogas and methane production is shown in Fig. 5.

The cumulative production of biogas and methane related to rice is equal respectively to 0.711 and 0.462 $Nm^3/kg{\cdot}SV$, with a maximum percentage of methane equal to about 65%. The trend in biogas and methane production is shown in Fig. 6.

3.3. Biogas vs. methane production

In Fig. 7 there is comparison of the biogas production between all the substrates used, allowing to identify which one of the substrates had a higher performance during the anaerobic digestion.

The highest biogas production was for cheese and biochar used as substrates and the lowest quantity of biogas was for coffee.

The production of methane between all the four substrates used, allowing to identify which one of the substrates had a higher performance during the anaerobic digestion is shown in Fig. 8.

The production of methane was similar as biogas production. The highest biogas production was for cheese and biochar used as substrates and the lowest quantity of biogas was for coffee.

It has not been easy to conduct a wide comparison with the present work because not many researches have been conducted on the anaerobic condition of the specific substrates used in this study. However, the performance of this study has been confirmed, by some previous works. Deublein and Steinhauser [26] described the amount of carbohydrates, proteins and lipids that the food should contain, to have a proper anaerobic digestion, and the effect of it on the production of biogas. Claiming that as higher the biomolecules present in the food, higher would be the production of biogas. As was shown during the present experiment, the

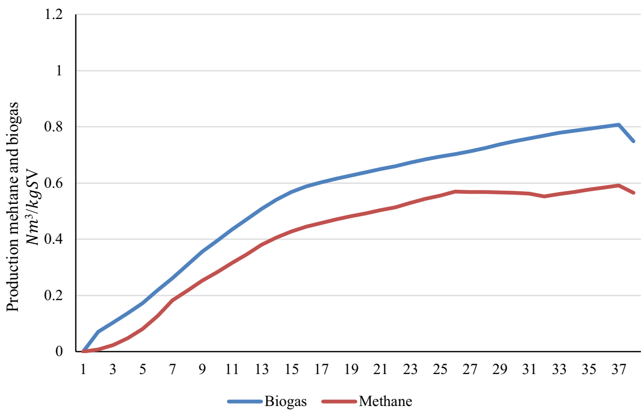

Fig. 2. Production of biogas and methane with cheese as a substrate.

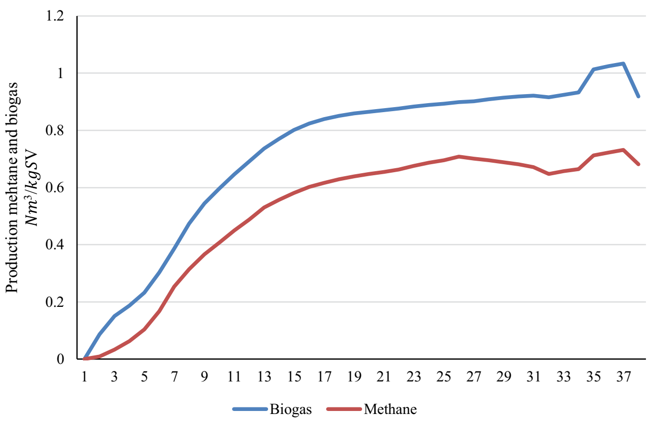

Fig. 3. Production of biogas and methane with cheese and biochar as a substrate.

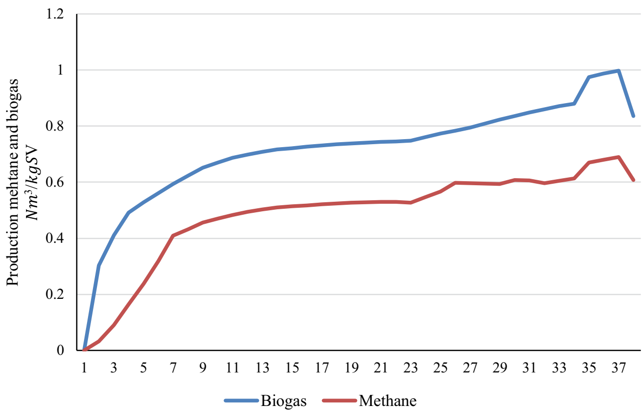

Fig. 4. Production of biogas and methane with dessert as a substrate.

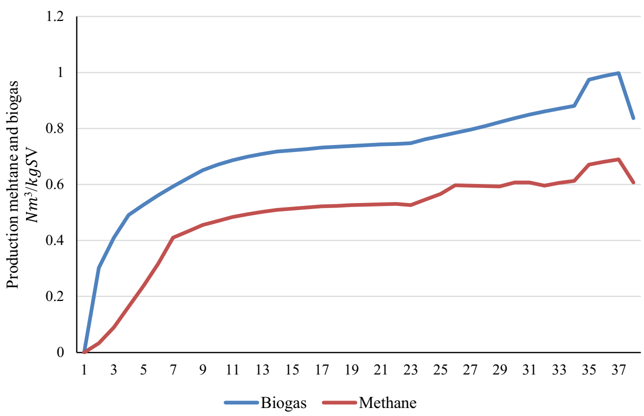

Fig. 5. Production of biogas and methane with spent coffee grounds as a substrate.

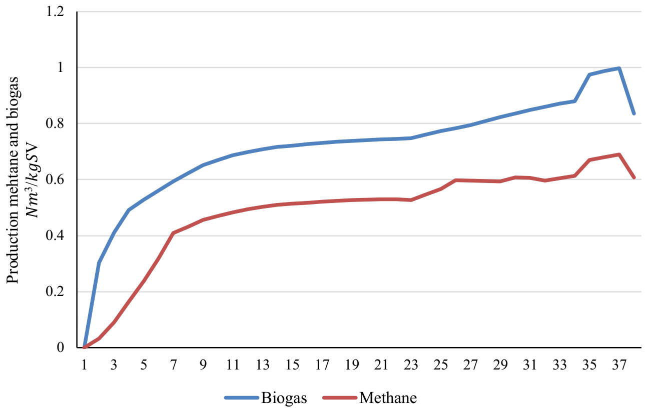

Fig. 6. Production of biogas and methane with rice as a substrate.

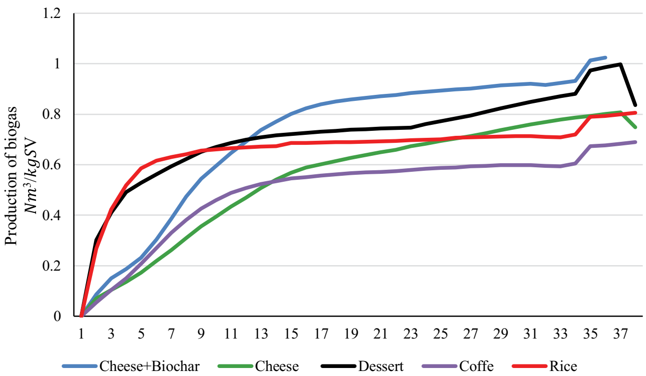

Fig. 7. Comparison of the biogas produced daily according to each substrate.

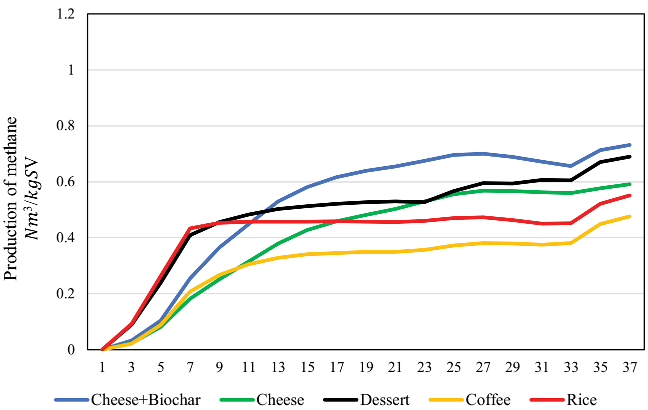

Fig. 8. Comparison of the methane produced daily according to each substrate.

cheese was the substrate that produced the highest amount of biogas. This was due to the high protein content on this substrate.

Shofie et al. [27] carried out experiments for the production of biogas, with coffee beans, however, the attempt to degrade the coffee grounds with anaerobic digestion failed. The reason of the failure during the anaerobic digestion was due the recalcitrant lignocellulosic composed of the substrates. The present results obtained were different, when spent coffee grounds was used as a substrate the production of biogas was successful. However, the SCG as a substrate produced the lowest amount of biogas comparing to the other substrates.

When biochar was added to cheese substrate, a remarkable increase on the biogas and methane production was noticed, increasing up to 23%. Sunyoto et al. [28] reported that the addition of biochar, in the two-phase anaerobic digestion of aqueous food waste with high carbohydrate content, shortened the phase of bacterial adaptation by 41%–45%, increased the maximum production rate by 23.0%–41.6% and CH_4 production potential of 1.9%–9.6%. Therefore, biochar has provided temporary substrate nutrients to support microbial metabolism and bacterial growth and regained pH, acting as a buffer and increasing the production speed of volatile fatty acids (VFA) and leading to a higher rate of CH_4 production.

The addition of biochar on the substrates allowed an easier biodegradability in the anaerobic digestion, due the conditions in which the bacteria strains are, thanks to the immobilization of the bacteria inside of the micropores of the biochar. Wang et al. [29] evaluated the buffering capacity of biochar, derived from vermicompost and used during anaerobic digestion of kitchen waste. He confirmed that biochar plays an important role in the digestion of easily biodegradable substrates and concluded that buffer capacity, biochar production and digestion performance are positively correlated with the proportion of biochar load.

The use of biochar as an adsorbent in anaerobic digestion has not yet been fully investigated, but biochar certainly has a positive impact both on the stability of the process and on the quality of the digestate produced. The addition of biochar during AD can reduce substrate-induced inhibition (SII: substrate-induced inhibition) and increase process stability, in three ways:

- increasing the buffering capacity of the system,
- through the absorption of inhibitors,
- through immobilization of bacterial cells.

Furthermore, the application of biochar improves the quality of the digestate, contributing to nutrient retention and reducing its leaching [30,31]. Such nutrients could be utilized for cultivation of plants biomass like microalgae [32,33].

4. Conclusions

The findings of this study showed that:

- Water protection and management of waste food are elements of the circular bioeconomy.
- The production of biogas obtained by the substrates used during this experiment (cheese, SCG, dessert and rice) showed a remarkable difference between them, due to the composition of each food.
- Due to high content of protein in cheese, the highest amount of biogas (76%) was produced.
- Biochar that was added to the cheese induces an increase on the biogas production of 0.153 $Nm^3/kg·SV$, and an increase of methane production of 0.135 $Nm^3/kg·SV$.

- The increase on the production of biogas and methane was observed due the conditions in which the bacteria strains are, thanks to the immobilization of the bacteria inside of the micropores of the biochar.
- The substrates that are composed of simpler nutrients and with a large amount of sugar such as rice and dessert presented a high production of biogas, for rice: 65.03%, and for dessert: 70.51%.
- The coffee had the lowest biogas production efficiency (63.15%), due to the simplicity of its composition.
- The future work is needed to asses the influence of the different dose of the biochar to the selected food waste.

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