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Improvement of Technologies of Biogas Production from Plant Waste

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Abstract. The research was performed with the aim of obtaining new data on effective methanogenesis during the fermentation of sugar production waste with the addition of lignocellulosic raw materials. Amaranth crops of different varieties were used as raw materials. After analyzing the component composition of fresh amaranth and dry raw materials according to standard methods, the samples were subjected to microbiological processing in the presence of an enzyme preparation in laboratory and industrial conditions. It was determined that when using the vegetative mass of amaranth plants with waste from sugar production in the processes of methanogenesis, the yield of biogas and its caloric content increase.

Introduction

Obtaining biogas from organic residues from agriculture is considered an important vector for the development of renewable energy. The potential of Ukraine in terms of biofuel production is huge, as the country has a well-developed agro-industry, the remains of which create a sufficient raw material base. Thus, energy obtained from biomass can become a tangible substitute for fossil fuels [1].

Taking into account the European experience, as well as the potential and needs of Ukraine in energy resources, the need for the construction of biogas plants involves three main factors:

- obtaining energy sources
- realization of agricultural products and by-products of biogas production
- management of environmental problems.

Therefore, the development of renewable energy, in particular the production of biogas, is of crucial importance for ensuring the energy security of Ukraine in the conditions of war.

More and more attention is paid in the world to the use of biowaste for the production of biogas by anaerobic fermentation [2,3]. The relevance of the development of this technology, as well as other technologies for the production of ecological energy resources, cannot be doubted, since energy consumption is constantly increasing, which will require an increase in the production of various types of energy carriers.

In agricultural regions, the operation of biogas plants is becoming widespread. Such installations are put into operation, as a rule, within the agro-industrial complex, with the close location of livestock fattening complexes, or plants processing plants, dairies, alcohol-vodka enterprises, etc. In conditions of high demand for electric and thermal energy, another problem arises for such enterprises - obtaining raw materials for the permanent operation of bio-installations. Such a problem is especially acute for seasonal productions, for example, for sugar factories, when raw materials for biogas production have significant fluctuations in their receipts throughout the year. It is possible to partially solve this problem if by-product waste is involved, or to increase the productivity of methanation with the same amount of involved waste. We suggested using plants that increase the degree of methanization of other waste in the mixture.

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Amaranth is a promising agricultural crop [4,5]. Its feature is a large increase in biomass, which allows you to get up to 500-600 quintals of cheap green plant material per hectare, even in conditions of depleted soils, and up to 2000 quintals per hectare in Podilla.

Amaranth oil acquires considerable nutritional and technical importance. The practical value of amaranth is also realized in the field of alternative energy technologies. It is interesting and promising to use this plant to increase the efficiency of biogas production by stimulating methanogenic microflora [6]. The ecological appeal of this culture also lies in the possibility of its cultivation in the sanitary zones of biogas production plants and near the fields of biological wastewater treatment, lagoons with digestate storage. In this case, we ensure closed functioning of ecological biotechnology.

In the context of the above, the *purpose of our research* was determined, which is the possibility of using amaranth in biogas production and using this data for the development of environmentally justified management methods.

Materials and Methods

To achieve the maximum intensity of biowaste fermentation in a biogas reactor, it is necessary to create the most favorable conditions for groups of microorganisms corresponding to each of the stages of fermentation, including at the stage of their preparation for loading into the reactor [5]. Plant substrates in their original form are quite difficult to undergo methane fermentation due to their physical and chemical structure.

Thus, the main components of plant raw materials participating in the four-stage methane fermentation (hydrolysis, acidogenesis, acetogenesis, methanogenesis) in the presence of anaerobic microorganisms are carbohydrates (lightly and heavily hydrolyzed polysaccharides - hemicelluloses and cellulose), proteins (vegetable proteins) and fats (oils). To achieve the maximum intensity of fermentation of biowaste in a biogas reactor, it is necessary to create the most favorable conditions for groups of microorganisms corresponding to each stage of fermentation, including the stage of their preparation for loading into the reactor [6].

The content of cellulose in plant raw materials is usually higher than that of easily hydrolyzed polysaccharides, which can cause the greatest time costs in biogas synthesis processes [7]. Lignin, present in plants, significantly complicates enzymolysis. To solve this problem, animal waste or additional enzymes for the destruction of lignin can be introduced into the enzyme complexes. It is advisable to structurally and chemically change plant agricultural waste in order to increase the intensity of microbiological treatment, for example, to additionally introduce plants with a high content of oils. Well-known methanization technologies when adding rapeseed to the main plant waste have gained practical application; rapeseed cultivation within the sanitary and protective zones of the enterprise is also quite common [8]. In our case, the company, which is part of the single complex of the sugar factory, uses rapeseed for the production of biodiesel at the available capacity. In addition, the ripening of amaranth takes place at the time of maximum exploitation of the capacities of the sugar factory, and it is possible to avoid additional costs for the storage of plant waste. Therefore, we suggest implementing the practical value of amaranth in the field of alternative production of biogas, which is poorer in fat content.

Industrial waste from sugar production was used as raw material - pulp, beet tops, molasses; as well as vegetative mass of amaranth plants and dried amaranth plant mass (temperature 60 °C, 4-5 hours in industrial dehydrators). Amaranth was grinded, mixed with the base in a ratio of 1:1 and the experimental mass was kept for 4 days. The obtained samples of amaranth were first analyzed, then the mixture was subjected to microbiological treatment with an enzyme complex of methanogenic bacteria in the laboratory.

The content of cellulose in the initial raw material and mixture was determined by the chlorous method, lignin by the sulfuric acid method; Nitrogen and Carbon - using the Primacs SNC-100 automatic analyzer, and then their mass ratio was calculated [4]. The moisture content of raw materials was determined by the standard weight method.

Microbiological processing of activated samples was carried out in the laboratory under the following conditions. Enzyme preparate – SUKAZYM ZH-1002 in the form of powder or diluted with distilled water up to a concentration of 8.3 g/l. Test samples were placed in the resulting solution to a concentration of 166 g/l, correspondingly, the total consumption of the enzyme preparation was 0.05 g/g of substrate. The pH value was maintained at the level of 6.5...7.5 at a temperature of 32...35 °C, without mixing and access to oxygen. The amount of gas produced was determined by the volumetric method every day. Gas samples were checked with a gas analyzer without stopping methanogenesis, at maximum and analyzed for the content of CO_2, CH_4, N_2, H_2. The experiment was considered finished when the daily gas output was less than 1% of the total output for 3 days (up to 40 days).

Results and Discussion

The results of the component analysis of vegetative and dried mass of amaranth are presented in Table 1.

Table 1. Chemical composition of the amaranth plant

Indicator	Vegetative mass of amaranth	Dried mass of amaranth
Cellulose,%	38,9	36,2
Sugar,%	4,5	5,8
Lignin	13,2	11,8
Ratio of Carbon : Nitrogen, mass parts	1:1,5	1:1,4
Raw material moisture, %	34	11,3

As shown by the results of Table 1, the cellulose during drying of amaranth remains thermally stable, as indicated by its slight quantitative decrease of 7,5% in terms of completely dry matter. A slight decrease in the concentration of cellulose in vegetable raw materials as the processing temperature increases may indicate the hydrolytic destruction of its amorphous part to disaccharoses, which is indicated by an increase in the sugar content. The fact of the destruction of the amorphous part of cellulose allows us to predict the intensification of enzymatic hydrolysis by cellulose complexes participating in the first stage of methanogenesis. A slight increase in lignin content was observed in dry amaranth. Since lignin belongs to polymers with a complex, disordered structure, its easily destructured forms undergo hydrolysis to low-molecular-weight fragments that can undergo a polycondensation reaction with each other, as well as with polysaccharides hydrolysis products, which contributes to the formation of new forms of lignin and lignosugars [9]. For methane fermentation, it is more acceptable to use raw materials with lower humidity, and the ratio of carbon and nitrogen was optimal for the two options.

Received substrates according to three options:

1. Control: a mixture of sugar production waste
2. A mixture of sugar production waste + amaranth green mass
3. A mixture of sugar production waste + amaranth dry mass

headed for the initial stage of methane fermentation. For all substrate samples, including the control one, the active release of biogas began on day 2...5. The daily yield of biogas was determined, the results of the research are presented in Figure 1.

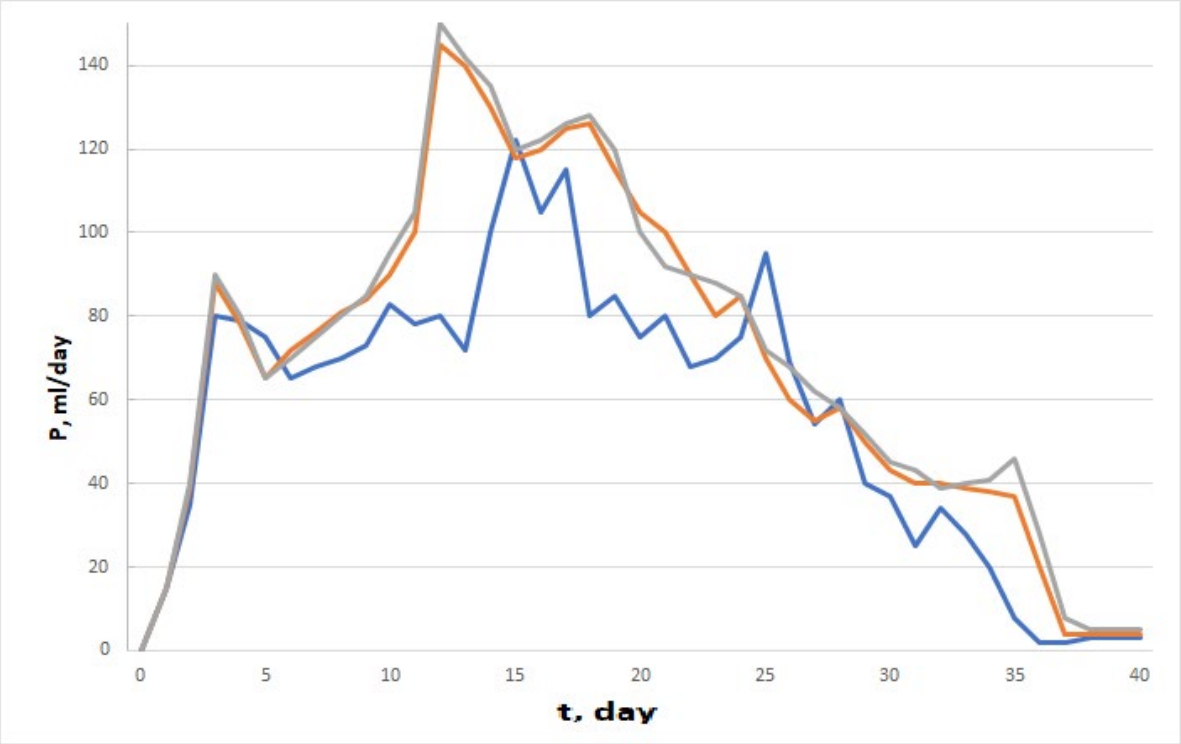


Fig. 1. Daily yield of biogas in laboratory conditions
—option 1; — option 2; — option 3.

The results indicate that the use of amaranth in the mixture led to a shift in the time of maximum biogas output to 13 (up to 150 ml/day), and in the untreated sample it was noted on 15th day (121 ml/day). Since the maximum output was observed in the exponential phase, in which the microorganisms consume the largest amount of nutrients, it can be concluded about the increased availability of the substrate for each option. After the onset of the peak, there was a natural decrease in the daily yield of biogas for the experimental samples, however, several peaks were also observed for the control sample. The nature of the curves of the experimental samples is very similar, with a slightly higher gas yield in the presence of dry amaranth in the mixture. The end time of the methanogenesis process for samples 1, 2 and 3 was 37, 39 and 40 days, respectively.

It was observed that the composition of biogas, and therefore its calorific value, changes over time. For the control option, the maximum yield of methane was observed on the 37th day (at the end of the methanogenesis process) and was 56%, for options 2 and 3 on the 30-32nd day and reached 60%. The average composition of biogas for three mixtures is given in Table 2.

Table 2. Composition of biogas obtained during fermentation of substrates

Option	CH_4	CO_2	O_2	N_2	CO
1	50	13	3	33	traces
2	55	11	2,5	29,5	traces
3	55	12	3	29	traces

Studies indicate that the use of amaranth in mixtures increases the calorific value of biogas, while a decrease in nitrogen content was observed. It can be assumed that methanization is partly due to the metabolism of methylamides [10].

The possibility of using Aztec amaranth as a raw material for biogas production together with sugar beet pulp in real industrial conditions was also investigated. The experiment was conducted with two options:

1. Control: beet pulp (moisture 80%)

2. Experiment: beet pulp with a similar moisture content and amaranth of fresh content in an approximate mass ratio of 1:1.

It was determined that when using the vegetative mass of amaranth plants with pulp in the processes of methanogenesis, the yield of biogas and its caloric content increase. As a result of our research, it was established that when beet pulp (control) and beet pulp with the addition of dry or fresh amaranth were used as a substrate, the gas yield differed slightly, within 8%, but the composition of the gas differed dramatically. On the 18th day of incubation, the methane content in the control was 54.5%, and in the experiment - 65.8% (Figure 2).

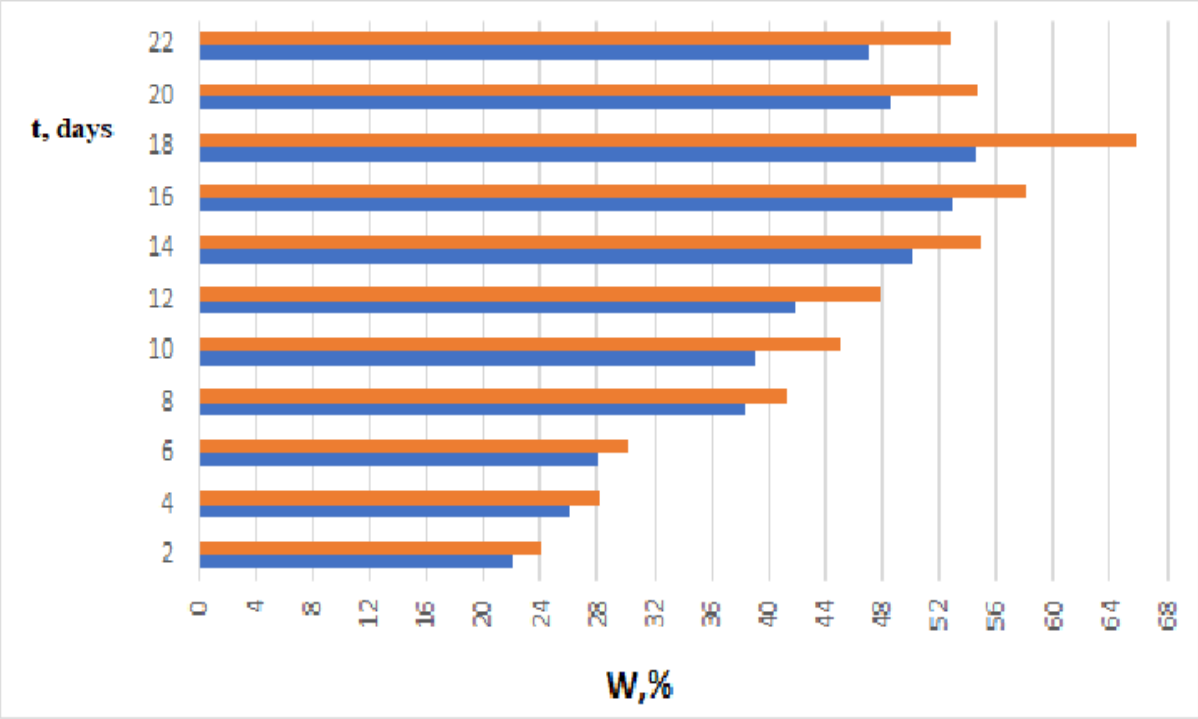


Fig. 2. Kinetics of methane release from a mixture of sugar beet pulp and amaranth: — Control, — Experiment

Further, this indicator decreases, which indicates the expediency of transferring biomass to the composter after 18-20 days. In the control sample, the maximum yield of methane was greater throughout the entire process. It follows that sugar beet pulp is fermented quite inefficiently, but in combination with amaranth is a favorable food resource for methanogenic microflora. Specialists claim that this combination is quite similar in character to the methanization of a mixture of sugar production waste and bird droppings, but in our case there are almost no gaseous compounds of secondary sulfur, which simplifies the technology of biogas production.

Conclusions

It is promising to use amaranth as a raw material to increase the efficiency of biogas production by stimulating methanogenic microflora and the possibility of growing the culture in the sanitary zones of biogas production plants, near the fields of biological wastewater treatment, lagoons with digestate storage.

Adding amaranth to the mixture of agricultural plant waste increases the bioavailability of raw materials, which allows generating 20-25% more biogas on the activated substrate.

The obtained results are of particular importance in the context of solving the problems of environmental and energy security, economic growth and contribute to a change in the level of development of the environmental consciousness of specialists in the agricultural sector.

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