

Reducing the emission of harmful gases from pig manure using different doses of biodestructors



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Abstract The anthropogenic impact of the functioning of livestock complexes on the environment is caused by the release of gaseous air pollutants into the atmosphere, including harmful gases such as methane (CH₄), carbon dioxide (CO₂), ammonia (NH₃), hydrogen sulfide (H₂S), nitrogen oxide (NO) and nitrous oxide (N₂O). The latter cause environmental degradation and have a negative impact on the climate balance of the planet. Therefore, the basis of the planned research was to evaluate the effectiveness of different doses of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors on the emission of harmful gases from pig manure *in vitro*. In the process of conducting experimental studies, it was established that the addition of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors to pig waste helps to reduce the level of CH₄ emissions up to 14.4% and 22.3%, NH₃ up to 23.7% and 39.7%, H₂S up to 22.2% and 38.2%, CO₂ up to 23.4% and 35.6%, NO up to 14.6% and 23.2%, respectively. Simultaneously, with the reduction of emissions of the studied gases, biodestructors also provide a lower level of pH, i.e., its shift to the acidic side up to 5.54 ("Scarabei") and 5.12 ("Vodohrai Chystyi Khliv"), against 6.2–6.5 – in the control. Thus, the results obtained indicate the feasibility of using the studied biodestructors, such as "Scarabei" and "Vodohrai Chystyi Khliv" at a dose of 40 g/m³ for lower emissions of harmful gases, both when storing manure in storage facilities (lagoons) and directly in the pig keeping premises, which will prevent the negative impact of intensive pig production on the environment.

Keywords: pig production, pollution, harmful gases, waste, biodestructors

1. Introduction

The activities of agricultural enterprises are characterized by the accumulation of a significant amount of animal origin byproducts (Johnson et al., 2007; MacLeod et al., 2013; Borodai et al., 2017). In particular, the pig industry is responsible for the accumulation of 39% of waste, i.e., it ranks second after cattle breeding (Pinchuk & Borodai, 2019). It is known that 1 kg of pork (with a live weight gain of 600 g per day) produces 11 kg of waste, which does not include water and litter that ends up in manure (Buzovsky et al., 2008). Natural microbiological processes begin to destroy manure, resulting in the continuous release of large quantities of volatile products from the decomposition of manure into the atmosphere, including greenhouse gases such as methane, nitrogen oxide and nitrous oxide, carbon dioxide, ammonia and hydrogen sulfide (Harper et al., 2000; Moller et al., 2004; Marszałek et al., 2018). According to the National Cadastre of Anthropogenic Greenhouse Gas Emissions, animal excrement is Ukraine's second largest source of greenhouse gas emissions. For example, methane emissions from pig manure decomposition are greater (3.19 kg/head/year) than are emissions from intestinal fermentation (1.5 kg/head/year) (Herman, 2009). Therefore, the development of the agrarian sector in general and pig production in particular cause serious problems in the field of environmental protection due to air, water and soil pollution (MacLeod et al., 2013; Zhukorskyi & Nikyforuk, 2013). Thus, an important aspect in addressing this issue is the greening of all livestock sectors, including pig production, which will reduce the negative impact of production, thereby preventing the disruption of the ecological balance in the environment.

Considering the importance of preventing environmental pollution caused by the activities of agricultural enterprises, a number of scientists have devoted their research to this issue. In particular, Sommer et al. (1993) used additional coatings such as oil, peat, chopped cereal straw, PVC film, pebbles of fired montmorillonite clay, and a lid as a means to reduce ammonia emissions from pig manure stored in tanks. The reduction in NH₃ emissions from livestock waste under wheat straw cover was explained by Xue et al. (1999) by a lower pH, i.e., a shift to the acidic side. Along with the above, other scientists have shown that straw causes an increase in the release of greenhouse gases from manure, such as CH₄ and N₂O



(Berg et al., 2006). Covering pig waste with clay pellets under cool, moderate and warm conditions (approximately 8°C, 11°C and 17°C, respectively) positively reduces ammonia emissions, with no impact on methane (Misselbrook et al., 2016). A literature analysis also revealed that mineral and vegetable oils applied as a liquid top layer to the surface of pig manure result in lower NH₃ emissions under laboratory conditions (Derikx & Aarnink, 1993). Research conducted by Jacobson et al. (1998) and Kim et al. (2008) revealed a significant reduction in H₂S from pig waste with soybean and essential oil, while rapeseed oil was ineffective (Ouellette et al., 2006). Lower levels of hydrogen sulfide emissions from pig manure were also observed with the addition of potassium permanganate and hydrogen peroxide (Smith & Nicolai, 2005). Moreno et al. (2010) used different doses of nitrite and molybdate as control agents for H₂S from pig manure in both open systems and in chambers, with the amount of application decreasing with increasing duration of waste storage. The surface application of soybean peroxidase and calcium peroxide to pig manure resulted in lower NH₃ levels by 14.6–67.6% and a significant increase in greenhouse gases—CH₄—by 32.7–232% and CO₂—by 20.8–124%, while the release of other gases, including H₂S and N₂O—did not significantly differ (Mauer et al., 2017). Chen et al. (2021) reported a greater effect on reducing ammonia and hydrogen sulfide emissions when mixing biochar powder manure than when mixing biochar pellets on a laboratory scale.

One of the possible ways to minimize ammonia emissions from livestock waste, particularly pig production, is to add acids by lowering the pH of the substrate under study, the most common of which is sulfuric acid (Fangueiro et al., 2015, Fuchs et al., 2021; Dalby et al., 2022). In particular, reducing the pH of manure to 5.5 by adding H₂SO₄ reduces the release of NH₃ from pig manure (Kai et al., 2008; Petersen et al., 2016). Other scientists have shown that sulfuric acid also reduces methane emissions (Petersen et al., 2014), while the acidification of waste has no positive effect on CO₂ and H₂S (Dai, 2013) or N₂O emissions (Petersen et al., 2016). The use of acids, particularly sulfuric acid, to prevent environmental gas pollution is dangerous, so in many countries, such as Portugal, the implementation of waste acidification is limited (Regueiro et al., 2013). However, when a mixture of water and sulfuric acid was sprayed on pig premises to maintain the pH at 5.5, a decrease in ammonia and dust concentrations was observed with greater live weight gain (Jensen, 2002). Research by Fuchs et al. (2021) proved the advantage of acidifying livestock waste with CH₃COOH compared to H₂SO₄, as it reduces emissions of not only ammonia and methane but also sulfur compounds, which can also increase when sulfuric acid is used. Acidification with a number of organic and inorganic acids, such as HNO₃, H₂SO₄ and H₃PO₄, is also known to reduce greenhouse gas emissions from pig manure, but nitric acid causes an increase in N₂O (Dalby et al., 2022).

Natural sorbents with high adsorption and cation exchange properties are widely used to prevent environmental pollution in the livestock industry and pig production. In the pig industry, natural sorbents such as zeolite (Portejoie et al. 2003), perlite (Berg et al., 2006), and basalt tuff (Broschak et al., 2018) are added to waste, which effectively reduces ammonia emissions but decreases greenhouse gas emissions.

For effective waste utilization in livestock production, preparations based on effective microorganisms are used; in particular, in pig production, "Bioprogress" preparation (Broschak et al., 2020) is used to neutralize the smell of ammonia and produce fertilizer. Research has shown that in pig premises, to ensure lower levels of NH₃, the "Alliance" additive was sprayed on manure stored under the floor, which led to a reduction in this gas of up to 24% (Heber et al., 2000). Additionally, based on the research conducted, the effective impact of the "ManureMax" additive on reducing methane emissions from pig waste was established, but the use of the latter is ineffective in reducing nitrous oxide and carbon dioxide emissions (Shah & Kolar, 2012). Thus, given the above, the literature focuses mainly on the adsorption of moisture from manure and the reduction of the level of emissions from pig waste from a separate gas, mainly ammonia or hydrogen sulfide, somewhat less often methane. At the same time, the negative impact on the environment caused by the emission of a complex of gases—CH₄, CO₂, H₂S, NH₃, and NO—remains relevant and poorly understood. Therefore, the search for means to reduce the level of environmental pollution by greenhouse gases from pig waste products (manure) is of great scientific and practical importance and is an urgent task of modern science.

The aim of this research was to evaluate the effectiveness of different doses of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors on the emission of harmful gases (CH₄, CO₂, H₂S, NH₃, NO) from pig manure *in vitro*.

2. Materials and Methods

Experimental studies on the effectiveness of different doses of biodestructors on the emission levels of harmful gases (CH₄, CO₂, H₂S, NH₃, and NO) from pig manure were carried out *in vitro* according to the methods of Skliar et al. (2019). To perform the experiment, samples of pig manure were taken from the State Enterprise "Experimental Farm Radekhivske" of the Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences of Ukraine. The research was conducted using electrochemical, mathematical, statistical and analytical methods. The experiment used hermetically sealed containers to ensure anaerobic conditions. To maintain the stability of the anaerobic fermentation process, the substrate moisture content was maintained at 92%. During the study, the temperature was within the psychrophilic regime.

To reduce the level of emission of harmful gases (CH₄, CO₂, H₂S, NH₃, NO) after passing through the hydrolysis, oxidation and acetogenesis stages on day 11, biodestructors were added to fermented pig manure (*in vitro*) at different doses, as follows: I – control (without introduction of additives); II – "Scarabei", 20 g/m³; III – "Scarabei", 40 g/m³; VI –

"Scarabei", 60 g/m³; V – "Vodohrai Chystyi Khliv", 20 g/m³; VI – "Vodohrai Chystyi Khliv", 40 g/m³; and VII – "Vodohrai Chystyi Khliv", 60 g/m³. Each variant of the experiment was repeated three times.

The "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures are made on the basis of highly active bacterial strains and organic fillers. The "Scarabei" biodestructor is composed of 3 strains of highly active bacteria—*Bacillus amyloliquefaciens* BS-18 IMB B-7470, *Cellulomonas flavigena* C-53 IMB B-7473, and *Rhodotorula glutinis* KR Zh-1 IMB Y-5056—and the carrier is corn grit in combination with wheat. The "Vodohrai Chystyi Khliv" biodestructor is enriched with natural strains of bacteria, such as *Bacillus subtilis*, *Bacillus licheniformis*, *Rhodococcus rhodochrous*, *Streptomyces albidoflvus*, and corn grit filler.

The above principle of normalizing the doses of the investigated biodestructors to manure was chosen on the basis of previous research with the introduction of their minimum and maximum values. The minimum dose of 10 g/m³ did not reduce the emission of harmful gases, which is in accordance with the control, and when 80 g/m³ of biodestructor was added to the manure substrates, only a tendency to reduce the emission of harmful gases was observed.

In the control and experimental groups, the levels of gases (CH₄, CO₂, H₂S, NH₃, and NO) were measured every three days after the introduction of the biodestructors for one month until the end of the study. The amount of emission of the investigated harmful gases during anaerobic fermentation of pig manure (*in vitro*) was determined using a Dozor S-M-5 gas detector analyzer (certificate of verification of a legally regulated measuring instrument No. 84709/92 and certificate of conformity No. UA.TR.002.CB.1234-19).

During the experimental studies, the substrate was mixed by intensive shaking of the containers. The conditions of the biofermentation process were similar in both the control variant, where anaerobic fermentation of the substrate occurred due to the natural microflora of manure, and in the experimental analogs with the introduction of different doses of biodestructors. The acidity (pH) was measured at the beginning and at the end of the experiment using a Tur N5170 pH meter.

The statistical analysis of the obtained research results was carried out by the methods of variation statistics using the standard *Microsoft Excel* and *AtteStat* application package using Student's t test. Differences between arithmetic means were considered significant at * P<0.05, ** P<0.01, and *** P<0.001.

3. Results and Discussion

Based on the analysis of the experimental data obtained during the research, the greatest reductions in the levels of emissions of harmful gases—CH₄, CO₂, H₂S, NH₃, and NO—from pig manure (*in vitro*) were achieved using different doses of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors on the 7th day of the research. The prolongation of this positive effect on reducing the emissions of the investigated gases from pig manure with the addition of different doses of biodestructors gradually decreased closer to the 31st day.

The results of the present study revealed a decrease in the level of ammonia release from pig manure (*in vitro*) when the "Scarabei" biodestructure was used at doses of 20 g/m³, 40 g/m³ and 60 g/m³ (ure 1) relative to that of the control, namely, on the 1st day, by 12.3% (P<0.01), 21.3% (P<0.01) and 6.8%, respectively, with an increase in the effectiveness of the effect on the 7th day, by 14.1%, 23.7% (P<0.01) and 8.3% (P<0.05), respectively, and on the last day of the experiment, by 5.6%, 8.4% and 1.2%, respectively. The introduction of the abovementioned "Vodohrai Chystyi Khliv" biodestructor into the investigated substrate under study reduced NH₃ emissions by 24.4% (P<0.01), 34.2% (P<0.001) and 7.5% on the 1st day, by 25.1% (P<0.001), 39.7% (P<0.001) and 8.7% on the 7th day, by 9.4% (P<0.05), 14.6% (P<0.001) and 0.8% on the 31st day of research, respectively (Figure 1).

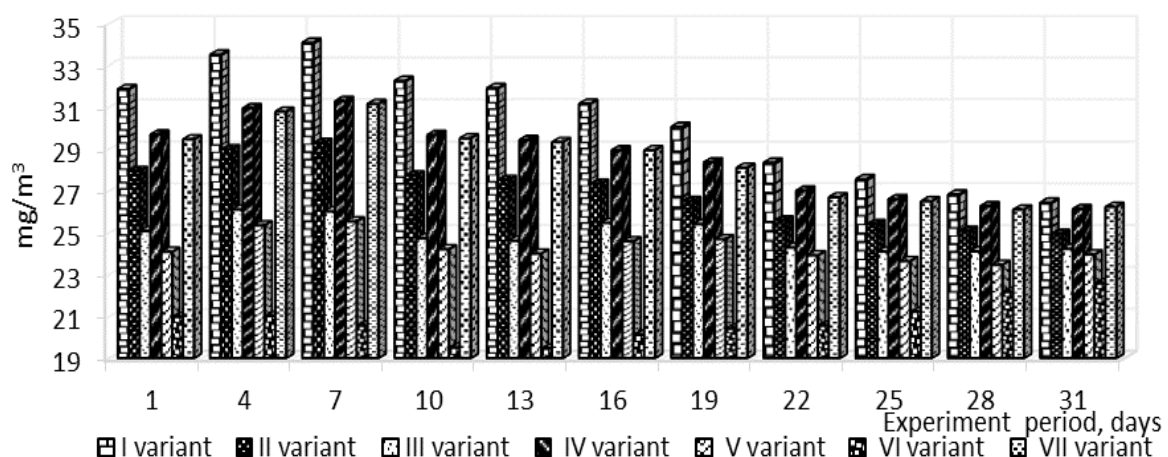


Figure 1 The level of NH₃ emission in the variants using different doses of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors.

The analysis of the results revealed a lower level of H₂S release (Figure 2) from pig manure (*in vitro*) in the presence of different doses—20 g/m³, 40 and 60 g/m³—of the "Scarabei" biodestructor, depending on the day of the research: on the 1st day, by 11.2% (P<0.01), 19.8% (P<0.001) and 7.9% (P<0.05); on the 7th day, by 12.6% (P<0.01), 22.2% (P<0.001) and 8.7% (P<0.01); and on the 31st day, by 0.4%, 5.5% (P<0.05) and 1.7%, respectively. The use of the "Vodohrai Chystyi Khliv" biodestructor reduced hydrogen sulfide emissions by 25.4% (P<0.001), 33.2% (P<0.001) and 11.7% (P<0.01) on the 1st day, 28.1% (P<0.001), 38.2% (P<0.001) and 14.6% (P<0.01) on the 7th day, 6.4% (P<0.05), 10.9% (P<0.01) and 4.4% on the 31st day, respectively.

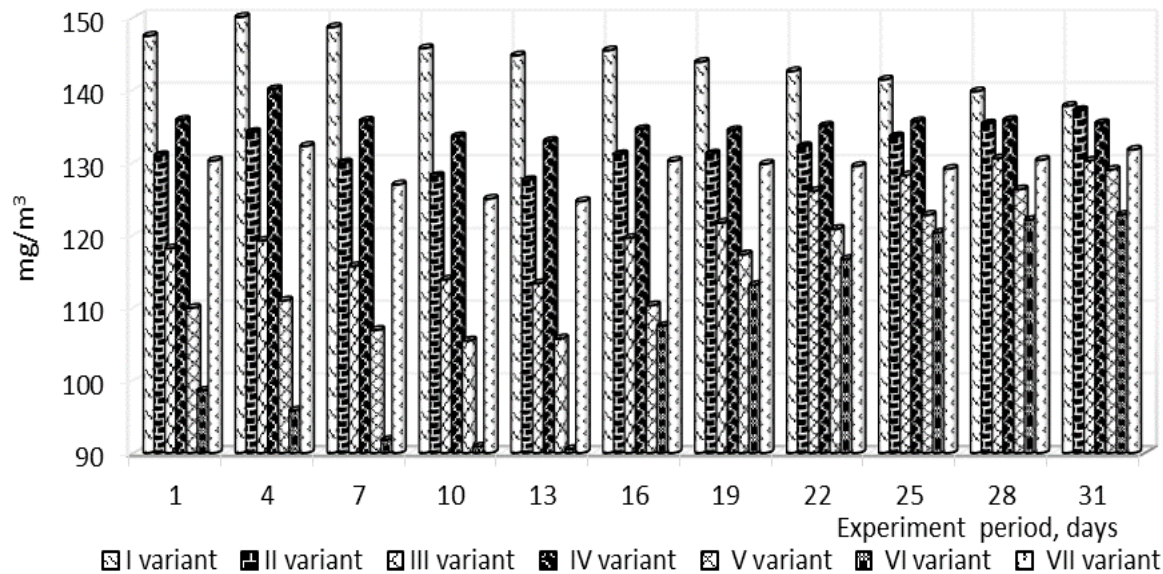


Figure 2 The level of H₂S emission in strains treated with different doses of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors.

Research has shown that the introduction of "Scarabei" biodestructor at doses of 20 g/m³, 40 g/m³ and 60 g/m³ reduces the level of nitrogen oxide release (Figure 3) from pig manure (*in vitro*) on the following days: 1st day, by 7.9%; 11.8%, by 7.7%; 7th day, by 8.4%; 14.6%, by 8.2%; and 31st day, by 1.1–2.2%. When the "Vodohrai Chystyi Khliv" biodestructor was added to pig manure in similar amounts, the emissions of the investigated gas decreased by 10.6%, 19.8% (P<0.05) and 6.2% on the 1st day, by 11.4%, 23.2% (P<0.05) and 7.1% on the 7th day, by 1.1%, 7.3% and 0.7%, respectively, on the 31st day of the research.

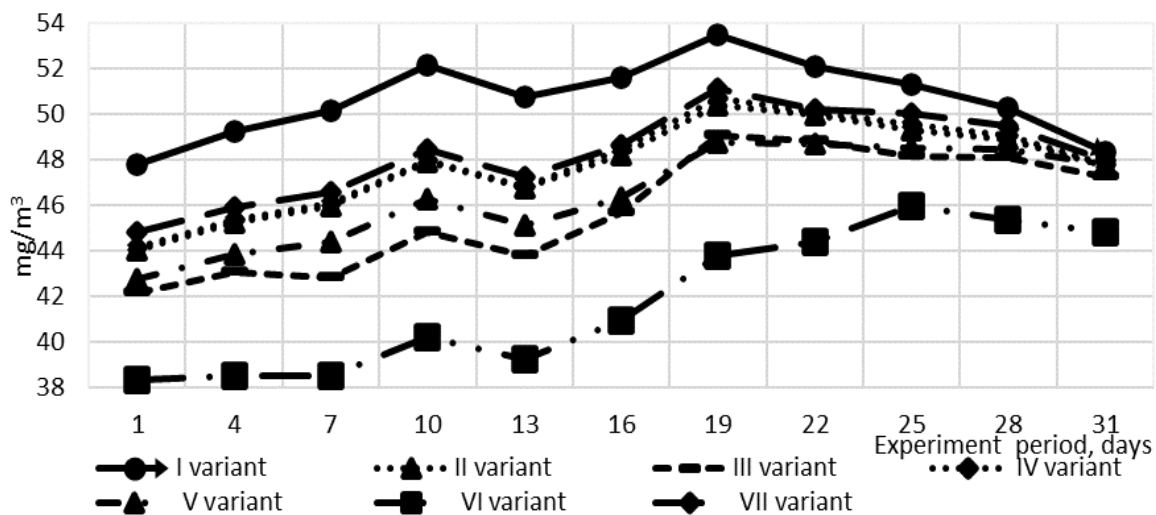


Figure 3 The level of NO emission in strains treated with different doses of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures.

The levels of methane emissions (Figure 4) during anaerobic fermentation of pig manure (*in vitro*) with the introduction of the "Scarabei" biodestructure at 20 g/m³, 40 g/m³ and 60 g/m³ were lower than those in the control group: 1st day, by 7.0%, 14.0% and 6.0%; 7th day, by 7.8%; 14.4% (P<0.05); and 6.4%, 31st day, by 0.6%, 5.2% and 0.3%, respectively. With the above doses of the "Vodohrai Chystyi Khliv" biodestructor, decreases in CH₄ emissions from pig manure were



observed, depending on the day: 12.0%, 21.7% and 9.8% on the 1st day; 12.9%, 22.3% (P<0.01) and 10.2% on the 7th day; and 5.2%, 7.2% and 3.3% on the 31st day.

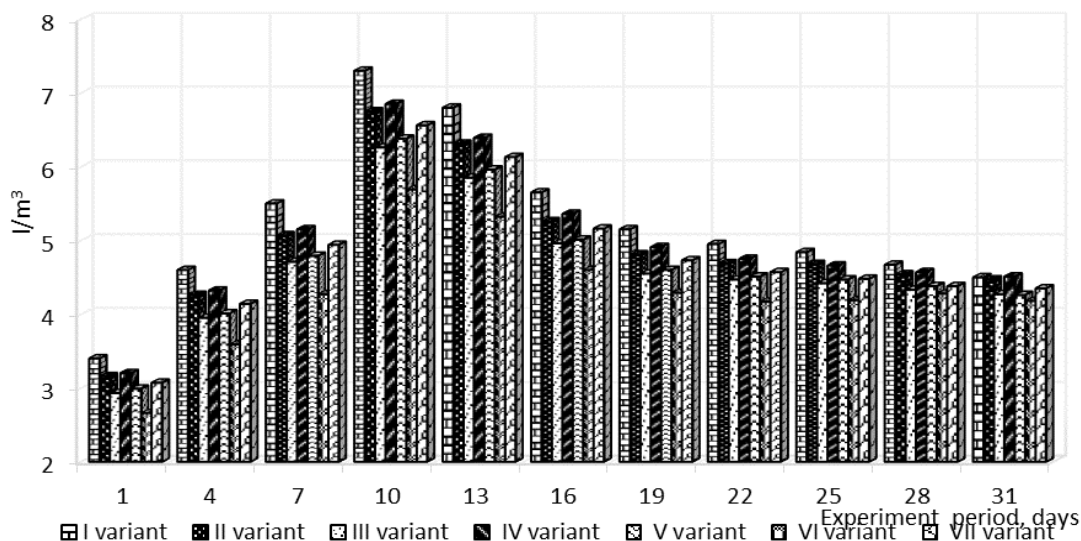


Figure 4 The level of CH₄ emission in strains treated with different doses of "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors.

According to the results of the present study, the addition of the "Scarabei" biodestructure at doses of 20 g/m³, 40 g/m³ and 60 g/m³ to the fermented pig manure substrate decreased CO₂ emissions (Figure 5) on the following days: 1st day, by 12.4%; 21.6 (P<0.05); 5.8%; 7th day, by 13.6%; 23.4 (P<0.05); 6.9%; and 31st day, by 5.2%, 7.9% and 0.3%, respectively. Similarly, the "Vodohrai Chystyi Khliv" biodestructure reduced carbon dioxide emissions from pig manure by 15.3%, 31.2% (P<0.05) and 7.6% on the 1st day; by 17.6%, 35.6% (P<0.05) and 9.0% on the 7th day; and by 7.2%, 10.5% and 1.8% on the 31st day, respectively.

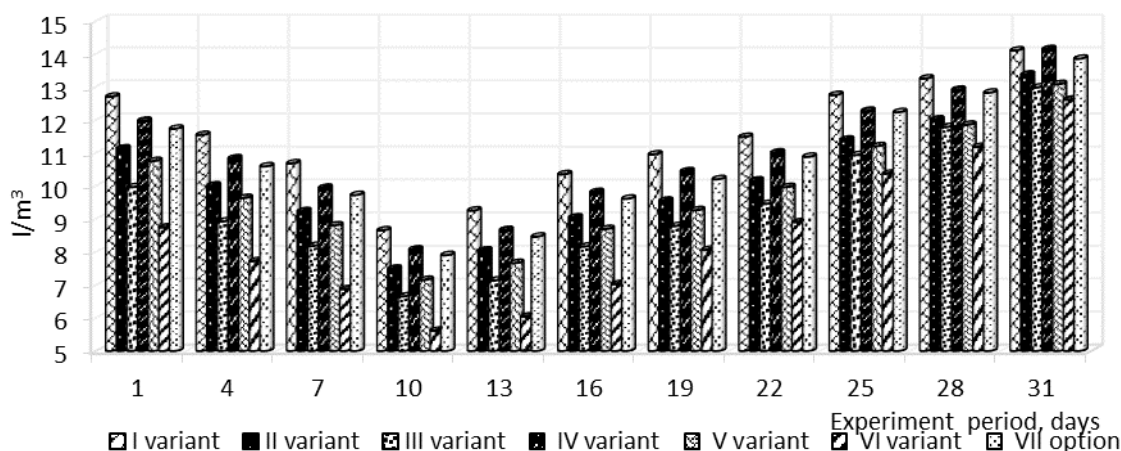


Figure 5 The level of CO₂ emission in plants treated with different doses of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures.

The analysis of the experimental data showed that, simultaneously with a decrease in the level of harmful gases from pig manure, the use of the investigated biodestructors inhibited fermentation processes, which was confirmed by a decrease in pH (Figure 6).

In particular, the pH of the pig manure in the control group during the experiment, both at the beginning and after its completion, ranged from 6.2–6.5. The introduction of the investigated biodestructures, such as "Scarabei" and "Vodohrai Chystyi Khliv", decreased the pH to 5.54 and 5.12, respectively. Summarizing the data obtained, it should be noted that at the optimal dose, the investigated biodestructors reduced the emission of harmful gases—CH₄, CO₂, H₂S, NH₃, and NO—from pig manure to the greatest extent and simultaneously provided the lowest pH.

The obtained experimental data indicated a positive effect on reducing the emission of the investigated gases at different doses (20 g/m³, 40 and 60 g/m³) of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors during anaerobic fermentation of pig manure (*in vitro*). On the basis of the results of the present study, it was experimentally proven that the greatest reduction in the emission of harmful gases from the investigated substrate was achieved by using the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures at 40 g/m³, while increasing the dose did not improve the emission. Notably,



among the investigated biodestructors ("Scarabei" and "Vodohrai Chystyi Khliv"), the most effective (22.3–39.7%) at reducing the level of harmful gases from pig manure (*in vitro*) was observed for the variants containing the optimal amount of the "Vodohrai Chystyi Khliv" biodestructor (40 g/m³). At the same time, a similar dose of the "Scarabei" biodestructure helped to reduce the emission of gases from the investigated substrate by 14.4–23.7% compared to that of the control. Thus, compared with the "Scarabei" biodestructor, the "Vodohrai Chystyi Khliv" biodestructor provides 7.9–16.0% lower levels of the harmful gases CH₄, CO₂, H₂S, NH₃, and NO from pig manure. It should be noted that the "Vodohrai Chystyi Khliv" biodestructor also had the most prolonged effect on reducing the emissions of the investigated gases from pig waste.

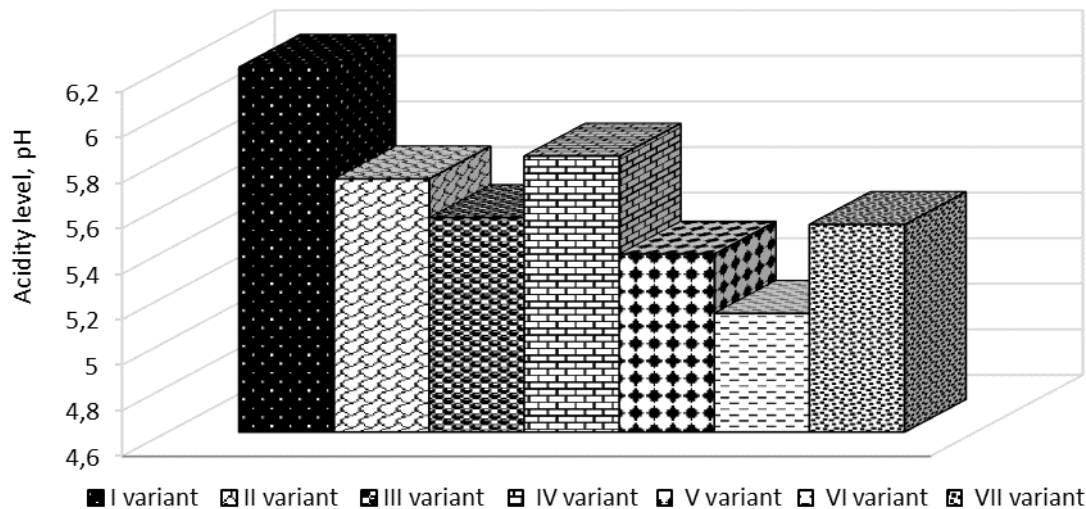


Figure 6 Acidity levels of strains treated with different doses of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures.

The positive effect of the above biodestructors on reducing the emission of the above harmful gases can be explained by the systemic impact of their components and the ability of microbial strains to reduce anaerobic processes. The microorganisms that are part of the investigated biodestructors help to improve the conditions and accelerate the biodegradation of organic material, reduce odors and eliminate toxic emissions, as they are better adapted and able to control the decomposition of products. These bacteria displace the microorganisms present in manure, thus deactivating the work of pathogenic and conditionally pathogenic microflora. Bacterial strains with biodestructors change the nature of their odor by hydrolyzing and biologically oxidizing compounds. Therefore, useful microorganisms multiply in waste, use organic matter as a source of energy, and suppress pathogenic microflora due to their numerical advantage, thereby ensuring an environmentally efficient process of waste disposal and conversion of the latter into organic fertilizers.

The control of ammonia, hydrogen sulfide, and greenhouse gas emissions is a complex problem associated with the pig industry. The data obtained during the experiment are in line with the research of Portejoie et al. (2003), who used oil, peat and zeolite under laboratory conditions to reduce ammonia emissions from pig manure. The positive effect of zinc oxide nanoparticles on reducing the level of ammonia and hydrogen sulfide emissions from pig manure was also established (Alvarado et al., 2015). A number of scientists have conducted studies under laboratory conditions on the reduction of ammonia emissions from the waste of pig production by adding granules, straw and rapeseed oil (Hörnig et al., 1999), as well as a number of acids—sulphuric, citric, lactic, acetic and aluminum sulphate (Regueiro et al., 2013)—but the latter are generally dangerous. Maurer et al. (2013) used different doses of biochar (1.14, 2.28, and 4.57 kg/m²), which significantly reduced ammonia emissions (12.7–22.6%), with a concomitant increase in methane emissions (22.1–24.5%) and no significant difference in the emissions of other gases, such as CO₂, N₂O and H₂S.

Thus, the results of this research indicate the potential of using the investigated "Scarabei" and "Vodohrai Chystyi Khliv" biodestructors at doses of up to 40 mg/m³ to reduce the emission of harmful gases both in pig premises and during the storage of animal byproducts in manure storage facilities (lagoons), which will minimize the negative impact of organic waste on the environment and thus increase the profitability and competitiveness of the pig industry.

4. Conclusions

The positive effects of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures on reducing the emission of harmful gases—CH₄, NH₃, H₂S, CO₂, and NO—from pig manure have been proven. The optimal effective dose (40 g/m³) of the "Scarabei" and "Vodohrai Chystyi Khliv" biodestructures for reducing the emission of harmful gases from pig waste *in vitro* was experimentally established. The "Vodohrai Chystyi Khliv" biodestructor had a greater impact on reducing the level of harmful gases from pig manure (*in vitro*) by 22.3–39.7% than did the "Scarabei" biodestructor by 14.4–23.7%.

The use of the investigated biodestructors will not only minimize the emission of harmful gases into the environment as a whole but also improve environmental standards on farms and thus improve the overall health of farm animals and their productive performance, opening up the potential for converting livestock waste in the form of excrement into highly concentrated organic fertilizers.

Hence, using the "Vodohrai Chystyi Khliv" and "Scarabei" biodestructures in the technological conditions of pig production will significantly reduce their negative impact (load) on the environment and thus help prevent negative changes in the climate balance of the planet and solve environmental problems.

Ethical Considerations

Not applicable.

Conflict of interest

The authors confirm that there are no conflicts of interest.

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