EMISSIONS OF GASEOUS POLLUTANTS FROM PIG FARMS AND METHODS FOR THEIR REDUCTION – A REVIEW

Anna Chmielowiec-Korzeniowska, Leszek Tymczyna*, Łukasz Wlazło, Beata Trawińska, Mateusz Ossowski

Department of Animal Hygiene and Environmental Hazards, University of Life Sciences,
Akademicka 13, 20-950 Lublin, Poland

*Corresponding author: leszek.tymczyna@up.lublin.pl

Abstract

Agriculture contributes significantly to anthropogenic emissions of greenhouse gases (GHG). Live-stock production, including pig production, is associated with several gaseous pollutants released into the atmosphere, including carbon dioxide (CO₂), methane (CH₄), ammonia (NH₃) and nitrous oxide (N₂O). Emissions of volatile organic compounds (VOC), including alcohols, aldehydes, and aromatic and aliphatic hydrocarbons, as well as typically odorous pollutants, are an inseparable element of raising and breeding farm animals. These emissions can degrade local and regional air quality, contribute to surface water eutrophication and acid rain, and increase the greenhouse gas footprint of the production sector. The paper is organized as follows. First, the sources and factors influencing the level of emissions from pig houses are described. Next, the effects of dietary methods (optimization of animal diets), hygienic methods (including microclimate optimization) and technological methods (application of technological solutions) for mitigating emissions from pigs are discussed.

Key words: carbon dioxide, methane, ammonia, VOCs, pig

The main cause of global climate changes is the emission of greenhouse gases (GHG), which in 2018 exceeded 3,893 Mt in the European Union alone, of which as much as 10% came from the agricultural sector (Eurostat, 2019). Emissions of gaseous pollutants from agricultural sources are a serious threat to the environment. They are not only an indicator of the sanitary state of air, but also significantly contribute to the acidification and eutrophication of terrestrial and aquatic ecosystems and to climate change (Herrero and Thornton, 2013). In case of agricultural activity, GHG emissions result from biological processes occurring on arable lands and permanent grasslands which include the cultivation of crops, organic and mineral fertilization, the decomposition of crop residues and the burning of grass (Syp, 2017). Livestock farms are an important source of their emissions.

Livestock production has a major share in the global greenhouse gas (GHG) balance, including carbon dioxide (CO₂), methane (CH₄), ammonia (NH₃) and nitrous oxide (N₂O) released into the atmosphere (Wang et al., 2018).

According to calculations by Gerber et al. (2013), global animal production accounts for 14–18% of GHG emissions and 64% of ammonia emissions. In Europe, as much as 94% of released ammonia comes from agriculture, of which 71% is associated with animal faeces management (Eurostat, 2016). The livestock sector accounts for an average of 53% and 21% of total methane and nitrous oxide emissions from agriculture (Sajeev et al., 2017).

Pork is the most widely consumed meat product in the world, and pig production is the second contributor of GHG emissions from livestock sector. Overall, GHG emissions from pig houses are estimated to 448.4 kg CO₂ equiv. per slaughter pig produced or 4.87 kg CO₂ equiv. per kg carcass. The fattening period accounts for more than 70% of total emissions, while the gestation, lactation and weaning periods each contribute to about 10% of total emissions (Philippe and Nicks, 2015).

Sources of emissions

The sources of released gaseous pollutants include the animals themselves, faeces (whether freshly excreted, remaining in channels, or stored in slurry tanks), feed, and technological equipment (Figure 1).

Figure 1. Sources of gaseous pollutants in animal facilities

Animals primarily emit CO_2 and NH_3 , and in smaller quantities trace gases such as alcohols, aldehydes, amines and sulphur compounds.

Carbon dioxide is a key greenhouse gas; its global warming potential (GHG) by definition is 1 (Marszałek et al., 2018). CO_2 emitted from pig slurry is generated during putrefaction and fermentation processes (aerobic and anaerobic decomposition of organic substances) taking place in pig slurry, as well as during hydrolysis of urea. Another source of CO_2 in piggeries is the animals' respiration. According to Philippe and Nicks (2015), fattening pigs excrete about 1.70 kg of carbon dioxide per day with exhaled air. Smaller amounts of CO_2 are released from manure during hydrolysis of urea and aerobic and anaerobic degradation of organic matter.

Methane is a dangerous greenhouse gas with global warming potential 21 times greater than that of carbon dioxide, and it is responsible for 18% of the global greenhouse effect (Mohajan, 2012). CH_4 released from pig slurry is produced by the anaerobic decomposition of organic matter by bacteria. This process takes place mainly (65–75%) during storage of pig slurry, but may also occur after its application in fields. CH_4 present in pig facilities is also generated as a result of bacterial fermentation in the large intestine of pigs (Marszałek et al., 2018).

The most methane is produced by ruminants, whose stomachs contain a large number of microbes that anaerobically break down plant fibre, which is resistant to digestive enzymes. Monogastric animals emit less methane than ruminants; as much as 86% of intestinal methane emissions come from cattle farms, and only 10% from pig production (Wang et al., 2018).

According to the International Panel on Climate Change (IPCC), in Western European countries, with an average annual temperature of 10–14°C, annual methane production from enteric fermentation amounts to 1.5 kg/pig, while production from manure is 9–12 kg/pig (IPCC, 2006).

The second important source of methane (10–15%) is the anaerobic breakdown of animal faeces. The volume of methane emissions from faeces is mainly influenced by the way they are stored, which is associated with temperature and oxygen access, as the largest quantities of this gas are produced in anaerobic conditions (Dämmgen et al., 2012). Factors that favour methane production also include high temperature, a high level of degradable organic matter, high moisture content, a neutral pH, and a C:N ratio of between 15 and 30 (Janus et al., 2016).

Another greenhouse gas is nitrous oxide, the main source of which is agriculture. In Poland, agriculture accounted for 78.7% of N_2O emissions in 2018 (Eurostat, 2019). The main source of N_2O emissions in agriculture is organically fertilized soil, on which plant debris left in the fields and animal excrement undergo degradation (Philippe and Nicks, 2015).

Nitrogen oxides can react with water vapour in the atmosphere to form nitric acid, which falls to the surface of the earth as precipitation, causing acidification of the environment and eutrophication of aquatic ecosystems.

The gas that causes the most problems in livestock farming is ammonia. Its emissions are one of the main factors increasing soil acidification. Although an aqueous solution of ammonia is alkaline, the compound causes significant acidification of the environment. This is due in part to oxidation in the atmosphere to nitrogen oxides,

which in contact with water are converted to nitric acid, but mainly to reactions with acids present in the environment and subsequent denitrification and nitrification taking place in the soil. Both of these processes, which are part of the natural nitrogen cycle, are accompanied by the formation of hydrogen ions and thus by an increase in acidification (Figure 2). Soil acidification leads to the dissolution and leaching of nutrients, macro- and microelements, and toxic heavy metals. Ammonia affects plant vegetation indirectly (by acidifying the soil) and directly (causing plasmolysis and cell death).

Figure 2. Ammonia reactions in air and soil

On farms with a high share of livestock production, the main source of ammonia emissions is livestock excrement, collected, stored and used in the form of solid manure and fermented urine or slurry. The release of ammonia depends on the presence of nitrogen compounds contained in animal excrement (amino acids, amides, urea and uric acid) and the activity of microorganisms. The most important factors affecting this process are the urinary urea concentration, pH and slurry temperature (Colina et al., 2000).

NH_3 concentrations in swine buildings show large variations and are related to a number of factors, including animal age, activity and density, outdoor temperature, ventilation control (Rodriguez, 2020). Ammonia emissions are obviously influenced by season with typically higher emission rates during summer time (about 7.0 g NH_3 /pig/day) and lower emission during winter time (about 3.0 NH_3 /pig/day). These results are explained by the greater ambient temperature and/or higher ventilation rate in summer time. Ammonia emissions are highly correlated with animal activity, and especially with feeding and excretory behaviour (Philippe et al., 2011).

An inseparable element of raising and breeding farm animals is emissions of volatile organic compounds (VOCs), including alcohols, aldehydes, and aromatic and aliphatic hydrocarbons, as well as typically odorous pollutants – phenols, indoles, amines, fatty acids and organosulphur compounds (Hansen et al., 2016; Opaliński et al., 2010; Chmielowiec-Korzeniowska, 2009; Chmielowiec-Korzeniowska et al., 2018). These gases are also released from the waste storage site (dunghills and open slurry tanks) and the land fertilized with them (Webb et al., 2010, 2014), and they cause a variety of undesirable reactions and even toxicity to people if the concentration exceeds a certain threshold (Orzi et al., 2018). VOCs are also important precursors of atmospheric photochemistry, some of which play a key role in the formation and production of atmospheric pollutants such as O_3 and secondary organic aerosol (Ziemann and Atkinson, 2012). Many VOCs form ground-level ozone by ‘reacting’ with sources of oxygen molecules such as nitrogen oxides (NOx) and carbon monoxide (CO) in the atmosphere in the presence of sunlight (Swamy et al., 2012).

In livestock buildings, the main sources of VOC emissions are feed, litter, and the animals themselves. An important factor in the transmission of these pollutants is organic dust. As the dust concentration in buildings increases, the amount of ammonia and odorous compounds and the number of microorganisms in the air increases as well. Odour from livestock facilities is related to the emission of several hundred different substances (odorants) into the air, especially carboxylic acids, phenols, aldehydes, ammonia and others (Chmielowiec-Korzeniowska et al., 2018; Mielcarek-Bocheńska and Rzeźnik, 2015).

Odorous substances identified on animal farms are classified into four main groups. Around dunghills, the sources of unpleasant odours are straight- and branched-chain volatile fatty acids, indoles and phenols, ammonia and volatile amines, and volatile sulphur compounds. Acetic, propionic and butyric acid are the most common volatile fatty acids (VFA) produced by microbial degradation of plant fibre and anaerobic fermentation of amino acids such as leucine, isoleucine, and lysine (Rechlarla et al., 2017). Volatile sulphur compounds (i.e. hydrogen sulphide, dimethyl sulphide, and carbonyl sulphide) are formed during the breakdown of sulphur-containing amino acids such as cystine and cysteine. Aromatic compounds such as phenols, cresols, indoles and skatoles are by-products of the degradation of tyrosine and tryptophan. These compounds are formed in the gut microbiota, as well as during anaerobic storage of pig manure. Nitrogen compounds, ammonia and volatile amines arise as a result of protein degradation, and thus the content of amino acids in the diet is the main factor affecting the production of odorous compounds in pig excrement (Chen et al., 2018). Cho et al. (2015) emphasize the close relationship between emissions of odorous compounds and the bacteria that colonize faeces.

Irrespective of the concentration, these compounds have an adverse local effect on air quality and reduce the quality of life of people living in the vicinity of farms. The scale of the problem is quite serious, as evidenced by the growing number of complaints regarding odour nuisance from farms reported to the Inspectorates of Environmental Protection (<http://sdr.gdos.gov.pl>).

Factors determining the volume of emissions

The volume of gases emitted depends on the animal species (Table 1), animal age and weight, the housing system and, above all, the number of animals kept in the building (Table 2). For every kilogram of animal body weight, 1 m³ of air per hour is released into the natural environment through ventilation systems. Hence the larger the scale of production, the greater the quantity of chemical and biological pollutants arising in the building, which increases the burden on the environment.

Table 1. Ammonia emissions factor for assessment in Poland (Sapek, 2013)

Animals	Emissions factor kg NH ₃ /animal/year
Dairy cows	27.8
Other cattle	12.5
Pigs	5.1
Sheep or goats	1.9
Poultry	0.26
Horses	12.5

Table 2. Dependence of the environmental burden on herd size (Walczak, 2017)

Number of animals	Herd of dairy cows		Herd of sows	
	emissions CO ₂ eq. (t)	emissions VOCs (kg)	emissions CO ₂ eq. (t)	emissions VOCs (kg)
20	252	1440	2	104
60	755	4320	6	312
120	1511	8640	11	624
240	3022	17 280	22	1248
480	6043	34 560	45	2496
700	8813	50 400	63	3640

Based on the literature reports regarding CO₂, CH₄ and N₂O production from animals and manure in pig houses, total GHG emissions are estimated at 4.87 kg CO₂ equiv. per kg carcass. The fattening period accounts for more than 70% of total emissions, while the gestation, lactation and weaning periods each contribute about 10% of total emissions (Philippe and Nicks, 2014).

Typically, gaseous emissions from pig houses present a diurnal pattern as a consequence of the comprehensive effects of temperature, ventilation rate and animal activity. Diurnal variation in ammonia and methane emissions is highly correlated with the diurnal variation in animal activity ($R_2 = 0.94$) and ventilation flow ($R_2 = 0.79$) (Blanes-Vidal et al., 2008). The highest emission rates are usually observed during feeding time (Moehn et al., 2004). For fattening pigs fed *ad libitum*, the first peak of emission occurs in the morning and a second peak in the afternoon (Philippe et al., 2014).

The location of fans in the building also modulates emission levels. Air inlets or outlets located near the manure surface increase the level of emissions due to greater air flow at the interface (Hayes et al., 2006). Zong et al. (2015) showed that the use of partial pit ventilation (PPV), i.e. ventilation with an extra pit-exhaust unit extracting a portion of the air directly from the emission source zone, substantially improves indoor air quality.

The type and amount of chemical pollutants generated is closely linked to the housing system (floor type), nutrition of the pigs and manure management.

Wang et al. (2011) confirm the relationship between emitted pollutants and the pig housing system. In fattening farms without litter, the authors recorded average ammonia emissions of 8.82 g/day/pig, whereas in a deep litter system, in identical conditions and at the same stocking density, the level was four times lower, at 2.16 g/day/pig. Comparison of the two systems showed significant differences in the concentration of odours expressed in odour units (OU). The average odour concentration in a pig house without litter was 105.4 OU, while in housing with deep litter it was only 67.5 OU. According to Nowakowicz-Dębek et al. (2017), keeping pigs on a slatted floor increases greenhouse gas emissions by as much as 65% and NH_3 by 78%.

Tymczyna et al. (2009) showed that pig farms without litter release more odorous compounds into the environment, including thiols and alcohols, but less methane. According to the authors, this is explained by the intensification of methanogenic processes in the litter, in which the temperature, oxygen availability, and pH create better conditions for the development of methane bacteria than in the slurry channels of a pig farm without litter.

The specific environment within the litter, especially the combination of aerobic and anaerobic areas, as opposed to strictly anaerobic slurry, explains these emission factors. Litter may differ in terms of bedding material, the amount and frequency of application, space allowance, litter management, and removal strategy. These parameters influence the physicochemical characteristics of the manure, such as density, humidity, temperature, pH, and C/N ratio, all of which interact to modulate gas emission levels (Philippe and Nicks, 2015).

A litter system with weekly manure removal and straw supply is associated with low NH_3 emissions (on average 6 g/day/pig) (Kavolelis, 2006). Osada et al. (1998) showed that weekly removal of manure reduced the levels of CH_4 and N_2O emissions by about 10% compared with the traditional deep-pit system. With the same removal strategy, Guarino et al. (2003) observed a 19% reduction in CH_4 emissions, but a doubling of N_2O emissions.

Frequent manure removal and separation of its solid and liquid fractions also reduce emissions of pollutants. Landrain et al. (2009) demonstrated that installing V-shaped scrapers under the grates can reduce ammonia and nitrous oxide emissions by 54% and 49%.

On slurry farms, emissions of gaseous pollutants can be reduced by lowering the slurry emitting surface. Some authors have observed a 7–13% reduction in CO_2 production after installing a partly slatted floor, compared with a fully slatted floor (Sun et al., 2008; Guingand et al., 2010). The use of a partly slatted floor has been shown to reduce cumulative emissions of GHGs (expressed in CO_2 equiv.) by 4–13%

compared with a fully slatted floor. Moreover, separation of faeces from urine by placing a belt conveyor at an angle of 4° under the floorboards (urine drains from the belt into a gutter leading to a closed storage vessel, while faeces remain on the belt for up to 24 h) may significantly reduce emissions of gaseous pollutants, including ammonia and methane (Koger et al., 2014).

The amount and type of gases released from faeces depends on the number and activity of microorganisms inhabiting them, substrate availability, environmental conditions, e.g. the presence of oxygen, faeces pH and consistency, and the means of removal (Naseem and King, 2018). Bacterial activity is poorly developed in fresh faeces. During storage, the number of microorganisms increases, and with it the level of volatile gaseous substances generated. Hence an important source of release of organic and inorganic gaseous compounds is waste storage sites, including dung-hills or tanks for liquid waste (fermented urine or slurry). In this case, the emissions depend on the way the pile is formed, its area, how well the tanks and channels are sealed, the use of absorbent and insulating materials, nitrogen content in the feed, and temperature conditions (Hansen et al., 2020).

Numerous transformations of nitrogen compounds take place in stored manure. The direction of these changes depends on multiple physical and chemical factors and on the number of microbes present in the manure, primarily the activity of uricolytic bacteria, which determine the quality of the manure as fertilizer. A rapid thermophilic phase with a C:N ratio of 0:1 results in the formation of slow-acting organic complexes of biogenic elements (Maeda et al., 2011).

Storage of animal faeces outside of buildings, in conjunction with their aerobic or anaerobic decomposition, can cause ammonia losses of up to 30%. Further ammonia losses take place during fertilization. Their volume depends on the type of excrement, the stage of plant growth, and the type of soil and plants being fertilized. An important factor determining the level of ammonia losses is the rate and technique of fertilizer application (Rütting et al., 2018).

Waste obtained on pig farms, including solid manure, fermented urine, and liquid manure, varies in consistency, chemical composition, bioavailability of minerals, and fertilizing effects. Waste management is one of the most important and most difficult problems on farms, especially large-scale farms. The development of industrial farming, which for economic reasons involves a housing system without litter, entails an increase in the production of manure in liquid form, i.e. slurry.

Legal regulations

Currently, livestock farms must meet quality and economic requirements, and at the same time they are required by Polish and European law to take into account the state of and impact on the natural environment.

The intensification of animal production ensures greater profits, but also increases the level of pollutants in the natural environment. For this reason livestock farms raising or breeding over 210 LSU are categorized as enterprises that can significantly affect the environment (Journal of Laws 2010 no. 213 item 1397).

Their activity is guided by the Best Available Techniques Reference Document (BREF), which contains requirements and recommendations for intensive pig and

poultry farming. The document requires the use of housing systems and techniques that entail the lowest possible emissions. The BREF was introduced by European Council Directive 96/61/EC of 1996 (IPPC Directive – Integrated Pollution Prevention and Control) (IPPC, 2008). The related document (the IPPC Directive) is the Commission Implementing Decision (EU) 2017/302 of 15 February 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the intensive rearing of poultry or pigs.

Methods for reducing emissions of gaseous pollutants

The dynamic development of animal production and high concentrations of animals in a small area create the need to develop methods to minimize the impact of farms on the natural environment. This process, however, must take into account all key aspects of raising and breeding livestock, legal requirements, and economic considerations. Intensive measures are currently underway in EU countries and in many American and Asian countries to reduce the scope of this phenomenon and improve environmental safety. The most important challenge for climate protection in agriculture is to introduce production methods that will help reduce greenhouse gas emissions.

The problem of reducing emissions of pollutants into the natural environment, especially ammonia emissions, can be solved in a number of ways: by optimizing animal diets (dietary methods) and litter quality (hygienic methods) and by applying appropriate technological solutions (technological methods) (Korczyński et al., 2010).

Dietary methods involve the optimization of feed composition or supplementation of the feed ration with various types of additives regulating the degree of excretion of biogenic compounds.

The techniques applied at the level of diet are aimed at improving the efficiency of absorption of nutritional compounds, which will reduce their content in faeces.

Supplying animals with excessive amounts of feed does increase production efficiency, but results in the excretion of excessive amounts of substrates with the faeces. Hence the main goal of dietary techniques is to improve the absorption of nutritional compounds. An important element of reducing losses of nitrogen (especially ammonia) and phosphorus to the environment is rational determination of protein requirements for fattened animals (e.g. phase feeding) and maximization of its utilization from feed.

Reducing the protein content in feed in combination with supplementation with essential amino acids (methionine, lysine, threonine and tryptophan) can significantly reduce the amount of nitrogen excreted without causing production losses. The formation of other protein fermentation products, such as fatty acids, hydrogen sulphide, and indolic and phenolic compounds, is reduced as well (Galassi et al., 2010; Chen et al., 2018). Reducing the level of crude protein in the diet of pigs by up to 12% can decrease the release of odorous compounds from manure by 40% (Cho et al., 2015).

Chen et al. (2018) showed a positive effect of a low-protein diet supplemented with alpha-ketoglutarate on the gut microbiota of pigs. The feed supplementation

increased the number of *Bacteroides* and *Bifidobacterium* bacteria, while reducing the number of *Escherichia coli* and the amount of ammonia generated in the caecum. In addition, the inclusion of organic acids, including benzoic acid, or fibre as feed additives reduces NH_3 emissions (Galassi et al., 2010; Eriksen et al., 2014). Unfortunately, an additional carbon source in feed enhances methanogenesis, thereby increasing the amount of methane produced (Philippe and Nicks, 2015). Eriksen et al. (2014), by adding benzoic acid to the diet of pigs, reduced ammonia emissions by more than 60%, while increasing the release of sulphur-containing compounds.

The positive effects of other biologically active substances, including probiotics, prebiotics and herbal preparations, are well known. Zhang and Kim (2014) demonstrated that a probiotic animal feed supplement containing the bacteria *Lactobacillus acidophilus*, *Bacillus subtilis* and *Clostridium butyricum* increases the absorption of amino acids and decreases the content of nitrogen compounds in the manure, thereby reducing ammonia emissions. Recharla et al. (2017) showed that the use of 0.2% symbiotics containing bacteria and yeast significantly reduces the amount of ammonia and hydrogen sulphide in the faeces.

Natural biologically active substances contained in herbs support a number of processes taking place in animals and facilitate nutrient uptake, thus exerting a beneficial effect on their metabolism (Valenzuela-Grijalva et al., 2017).

Bartoš et al. (2016), by supplementing pig feed with a mixture of essential oils, obtained a significant decrease in ammonia emissions, which they ascribed to inhibition of urease activity.

Saponin preparations containing extract of the *Yucca schidigera* plant have similar effects. These compounds are successfully used to control ammonia generated in animal housing, as well as to reduce its release from animal faeces. The use of this plant extract in animals feed improves metabolic efficiency (Alagawany et al., 2016).

According to Saeed et al. (2018), these compounds inactivate urease, which is responsible for the breakdown of urea into ammonia. The authors suggest that the active substances contained in the *Yucca schidigera* extract inhibit the growth of uricolytic bacteria. Chepete et al. (2012) found that saponins bind the ammonia, thereby reducing its release from faeces. The authors showed that the use of saponin extract of feed reduces the amount of ammonia released from poultry droppings by 28–44%. Mroczek (2009) obtained similar effects by enriching the diet of fattening pigs with saponin extract.

All these observations support the hypothesis that phytochemical feed additives can have a beneficial effect on intestinal function. The benefits of prebiotics in pig diets are most often associated with increased synthesis of short-chain fatty acids (SCFA). Increasing the concentration of SCFA raises the intestinal pH and reduces the rate of protein fermentation in the gut (Lindberg, 2014; Roberfroid et al., 2010). Lactulose also has a stimulating effect on the growth and/or activity of the intestinal microbiota. It is broken down in the large intestine into lactic and acetic acid, which stimulate the growth and activity of *Bifidobacterium* and *Lactobacillus* bacteria and reduce the activity of proteolytic bacteria. Immobilization of proteolytic bacteria reduces the release of ammonia into the external environment. Acidifiers improve nu-

trient digestibility in the small and large intestine, thus increasing nutrient retention (Papatsiros and Billinis, 2012).

Other prebiotics of interest to scientists are oligosaccharides, including oligofructose and inulin. Dietary supplementation with inulin has a positive effect on SCFA production and reduces the generation of putrefactive fermentation products, thereby reducing the amount of odorous compounds released. Studies show that a diet for piglets with 4% inulin increases the share of lactic acid bacteria and bifidobacteria in the intestines (Tako et al., 2008). Pierce et al. (2005) found that a 1.5% inulin supplement in the diet of piglets significantly improved feed digestibility, and thus reduced the amount of nitrogen excreted into the environment.

Grela et al. (2016) emphasize that oligosaccharides included in animal diets improve their health. By stimulating the natural gut microbiota, they inhibit the growth of pathogenic and putrefactive bacteria such as *Salmonella*, *Clostridium difficile* and *Escherichia coli*. Van de Wiele et al. (2007) showed that the use of inulin resulted in greater SCFA production, a higher number of *Bifidobacterium* spp., and a longer-lasting bifidogenic effect than the addition of oligofructose, which has a lower degree of polymerization.

Irrespective of the type of supplementation used, assessment of nutrient utilization efficiency and the impact on the amount of pollutants emitted requires a comprehensive approach to the problem that takes into account the environmental and economic value of the method used.

Hygienic methods used to control the emission of gaseous pollutants from farms are presented in many studies. The methods described include measures to reduce the generation of pollutants in livestock buildings and during manure storage and to limit their spread.

There are two basic principles of odour control: reducing odours at the source and removing them from the gas stream before they are dispersed in the atmosphere. The first goal can be achieved using dietary supplements that reduce odours released from faeces (Eriksen et al., 2010; 2014), while odours that have been emitted can be removed by various treatments, such as changing the physicochemical properties of faeces using various types of additives improving their hygienic quality (Korczyński et al., 2010).

It is crucial to ensure optimal temperature and humidity conditions in livestock buildings (by means of properly functioning ventilation and heating) and to maintain hygiene by efficiently draining animal manure and the water used to clean the buildings, as well by using smooth, easy-to-clean surfaces. In buildings with a system without litter, replacing concrete, porous slats with cast iron, metal or plastic can reduce NH_3 production by 10–40% (Philippe and Nicks, 2015). The gas-emitting area can be reduced by decreasing the area of the slatted floor. Frequent addition of litter and removal of contaminated material, as well as systematic flushing of slurry channels is not without significance (Sommer et al., 2006).

An effective way to reduce the concentration of pollutants in livestock buildings is to reduce the dust concentration in the air by fogging or spraying the litter with oil. Adding disinfectants and acidifiers to the litter and faeces reduces the number of bacteria that inhabit it, including uricolytic bacteria, thus affecting the amount of ammonia released.

Faecal pH is one of the most important factors determining the concentration of ammonia in the aqueous phase, and thus affects the release of this gas. Studies have shown that the release of ammonia from litter begins at a pH of about 7, and reaches a maximum value of 8 or higher (Monteiro et al., 2010).

Research by Kai et al. (2008) showed that lowering the pH of slurry to below 6 reduced ammonia release by 70% at the site of its formation, i.e. on the pig farm, by about 10% during its storage, and by 67% during its application as fertilizer. Petersen et al. (2012) indicate that acidification of faeces also reduces methane. Wang et al. (2014) showed that acidification of the swine slurry to pH 5.5 resulted in a reduction of CH₄ emissions by 80.8% and NH₃ emissions by 40.2%, but increased H₂S emissions by 11.3%.

The use of sulphuric acid for acidification increases the concentration of inorganic sulphur in slurry, which may increase hydrogen sulphide emissions. Eriksen et al. (2014), however, emphasize that low pH inhibits the growth and activity of microorganisms colonizing faeces, and thus reduces the amount of pollutants released.

Much attention has recently been focused on natural sorbents of gaseous pollutants. Aluminium silicates (natural and synthetic) have found the widest application. These include zeolite, bentonite and perlite, which have the ability to absorb water (to dry the litter) and gases without changing their structure. The addition of aluminosilicate or humic material to litter reduces the emission of odorants from the substrate to the air. This is confirmed by the research of Opaliński et al. (2010).

As an alternative to chemical approach, biological treatments, which include blends of enzymes, enzyme inhibitors and/or microorganisms, are increasingly used (Pezzuolo, 2019).

The addition of enzymes (Gungor et al., 2016) or bacteria accelerating the mineralization of odorous compounds (Matusiak et al., 2013) in faeces has proven effective. Matusiak et al. (2013), in a study assessing the effect of bacteria isolated from soil on the decomposition of isobutyric acid, dimethylamine, trimethylamine and hydrogen sulphide, i.e. compounds present in chicken manure, have shown that *Bacillus subtilis*, *Bacillus megaterium* and *Pseudomonas fluorescens* are able to reduce the content of these compounds by as much as 49.8%.

The quantity of pollutants released is largely determined by the physicochemical properties of the faeces. The selection of litter material or the presence of organic material in the slurry determines the rate of microbial transformations taking place in them.

One way to reduce the release of ammonia is to increase the amount of litter under the animals. The addition of litter material improves the C:N ratio and additionally aerates the litter, which promotes bacterial growth and N assimilation. Jiang et al. (2011) showed that the C:N ratio could affect the NH₃ and CH₄ emissions significantly, but not the N₂O. An unfavourable C:N ratio in excrement and manure causes them to become mineralized too quickly and leads to poor nitrogen retention.

Technological methods used in livestock farming include measures to optimize the microclimate of livestock housing and techniques to reduce emissions of pollutants into the environment. These methods also apply to slurry storage and management methods (Wang et al., 2011; 2014; Ershadi et al., 2020).

One parameter that affects emissions of gases from slurry is temperature (Miselbrook et al., 2016), so installations that lower the slurry temperature are used when it first flows from livestock buildings in the floor under the slats. Moreover, installing a spray system in slurry channels and spraying them with acids reduces the pH of the suspension, and thus the amount of ammonia released.

Another technology for slurry treatment is aeration. This technology neutralizes odours and blocks methane formation (Calvet et al., 2017). Mostafa et al. (2020) reduced greenhouse gas emissions by aerating the slurry. Test results indicate that the highest mitigation potentials were 12.0, 57.6, and 10.4% for nitrous oxide, methane, and ammonia, respectively.

An important element of prevention of the spread of pollutants from waste storage sites (both solid and liquid manure) is the use of physical barriers. Materials used to cover the top layer of slurry in the tank include pellets, e.g. perlite or zeolite, chaff, various oils, plastic foil, peat, and other materials that float on the surface of slurry. The effectiveness of these materials in reducing odorous gas emissions is as high as 90% (Berg et al., 2006).

Good effects in livestock buildings can be obtained using ultraviolet radiation, negative air ionization, ozonation (Bildsoe et al., 2012; Liu et al., 2011), or a phyto-tron chamber (Domagalski et al., 2012), by fogging the air, or by spraying the litter with oil, which reduces the dust concentration in the air and thus the level of pollutants. These techniques have generally not been adopted in practice, although they are effective and do not require complicated installation. Some of them (ozone and UV radiation) pose some danger to animals and their handlers. In addition, UV rays do not reach the deeper layers of manure. In these layers, saprophytic microflora will continue to develop despite the treatment, transforming biogenic compounds into odorous gases (Oleksy et al., 2015).

Very good results in the removal of impurities after their formation are achieved using biological methods, including biofiltration. These methods are also included in the BREF Reference Document as recommended BAT techniques to reduce pollutant emissions.

Biofiltration is the filtration of air discharged from the building via ventilation devices by the biologically active filtration material in biofilters (Tymczynna et al., 2010). When pollutants come into contact with the population of microorganisms, including bacteria, fungi and actinomycetes, naturally occurring or intentionally introduced into the filtration material, gaseous air pollutants are partially or completely decomposed. Research in pig houses has shown that the reduction in VOCs may exceed 80% (Tymczynna et al., 2010).

Filtering polluted air in devices called scrubbers can produce good results. Feilberg and Sommer (2013) confirm that both chemical and biological scrubbers can reduce NH_3 emissions. Estimates show, however, that the use of chemical scrubbers can reduce NH_3 emissions by $90 \pm 8\%$, while safer biological scrubbers (without aggressive reagents) achieve reductions of only $46 \pm 40\%$. In the case of chemical scrubbers, the addition of acid (usually sulphuric acid) lowers the pH of the scrubbing water, which absorbs dissolved NH_3 to form an ammonium salt solution (Van der Heyden et al., 2015).

Conclusions

Effective reduction of greenhouse gas emissions from pig production can be achieved by creating a suitable microclimate in the piggery (hygienic and technological methods), as well as by implementing a suitable feeding strategy (dietary methods). The works cited in this review indicate that hygienic and technological methods have measurable benefits, but their selection and application should take into account the animals' bioclimatic requirements in terms of comfort and the specific characteristics of the housing system. Furthermore, their implementation should encompass the entire production cycle. Unfortunately, investment and operating costs in the current market situation may be hindrances to their application.

Diet manipulation taking into account the needs of pigs in accordance with their physiology and stage of growth not only reduces emissions of pollutants, but is easy to implement and economically viable.

To sum up, it is not possible to discuss all methods of controlling pollution from livestock farms. It is important for applied research to comprehensively consider their environmental and economic potential. The methods should cover all stages of the formation of these pollutants, while further development of livestock farming without taking into account the burden on the environment caused by greenhouse gases seems impossible. Despite numerous studies and applications, work on new, effective methods to reduce emissions of pollutants from livestock is still ongoing.

Conflict of interest

The authors declare no conflict of interest

References

- Alagawany M., Abd El-Hack M.E., El-Kholi M.S. (2016). Productive performance, egg quality, blood constituents, immune functions, and antioxidant parameters in laying hens fed diets with different levels of *Yucca schidigera* extract. *Environ. Sci. Pollut. Res.*, 23: 6774–6782.
- Bartoš P., Dolan A., Smutný L., Šístková M., Celjak I., Šoch M., Havelka Z. (2016). Effects of phytogenic feed additives on growth performance and on ammonia and greenhouse gases emissions in growing-finishing pigs. *Anim. Feed Sci. Technol.*, 213: 143–148.
- Berg W., Brunsch R., Pazsiczki I. (2006). Greenhouse gas emissions from covered slurry compared with uncovered during storage. *Agr. Ecos. Environ.*, 112: 129–134.
- Bildsoe P., Adamsen A.P.S., Feilberg A. (2012). Effect of low-dose liquid ozonation on gaseous emissions from pig slurry. *Biosys. Eng.*, 113: 8693.
- Blanes-Vidal V., Hansen M.N., Pedersen S., Rom H.B. (2008). Emissions of ammonia, methane and nitrous oxide from pig houses and slurry: Effects of rooting material, animal activity and ventilation flow. *Agric. Ecosyst. Environ.*, 124: 237–244.
- Calvet S., Hunt J., Misselbrook T.H. (2017). Low frequency aeration of pig slurry affects slurry characteristics and emissions of greenhouse gases and ammonia. *Biosyst. Eng.*, 159: 121–132.
- Chen J., Kang B., Jiang Q., Han M., Zhao Y., Long L., Fu C., Yao K. (2018). Alpha-ketoglutarate in low-protein diets for growing pigs: effects on cecal microbial communities and parameters of microbial metabolism. *Front. Microbiol.*, 9: 114.
- Chepete H.J., Xin H., Mendes L.B., Li H., Bailey T.B. (2012). Ammonia emission and performance of laying hens as affected by different dosages of *Yucca schidigera* in the diet. *J. App. Poultry Res.*, 21: 522–530.
- Chmielowiec-Korzeniowska A. (2009). The concentration of volatile organic compounds (VOCs) in pig farm air. *Annal. Agric. Environ. Med.*, 16: 249–256.

- Chmielowiec-Korzeniowska A., Tymczyna L., Pyrz M., Trawińska B., Abramczyk K., Dobrowolska M. (2018). Occupational exposure level of pig facility workers to chemical and biological pollutants. *Ann. Agric. Environ. Med.*, 25: 262–267.
- Cho S., Hwang O., Park S. (2015). Effect of dietary protein levels on composition of odorous compounds and bacterial ecology in pig manure. *Asian Austral. J. Anim. Sci.*, 28: 1362–1370.
- Colina J., Lewis A., Miller P.S. (2000). A review of the ammonia issue and pork production. *Nebraska Swine Rep.*, 108: 2425.
- Commission Implementing Decision (EU) 2017/302 of 15 February 2017 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for the intensive rearing of poultry or pigs.
- Dämmgen U., Schulz J., Klausing H.K., Hutchings N.J., Haenel H.D., Rösemann C. (2012). Enteric methane emissions from German pigs. *Landbauforschung Volkenrode*, 62: 83–96.
- Domagalski Z., Marek P., Sobczak J. (2012). The use of a phytotron chamber in reducing emissions of odor compounds from poultry houses. *Probl. Agric. Eng.*, 2: 127–131.
- Eriksen J., Adamsen A.P.S., Norgaard J.V., Poulsen H.D., Jensen B.B., Petersen S.O. (2010). Emissions of sulphur-containing odorants, ammonia, and methane from pig slurry: Effects of dietary methionine and benzoic acid. *J. Environ. Qual.*, 39: 1097–1107.
- Eriksen J., Nørgaard J.V., Poulsen H.V., Jansen B.B., Petersen S.O. (2014). Effects of acidifying pig diets on emissions of ammonia, methane, and sulfur from slurry during storage. *J. Environ. Qual.*, 43: 2086–2095.
- Ershadi S.Z., Dias G., Heidari M.D., Pelletier N. (2020). Improving nitrogen use efficiency in crop-livestock systems: A review of mitigation technologies and management strategies, and their potential applicability for egg supply chains. *J. Clean. Prod.*, 265: 121671–121675.
- Eurostat 2016. Share of agriculture to total ammonia emissions. Available online: [http://ec.europa.eu/eurostat/statisticsexplained/index.php/File:Share_of_agriculture_to_total_ammonia_emissions,_\(%25\),_2010,_EU-27.png](http://ec.europa.eu/eurostat/statisticsexplained/index.php/File:Share_of_agriculture_to_total_ammonia_emissions,_(%25),_2010,_EU-27.png).
- Eurostat 2019. Greenhouse gas emissions by source sector (source: EEA). Available online: https://ec.europa.eu/eurostat/databrowser/view/env_air_gge/
- Feilberg A., Sommer S.G. (2013). Ammonia and malodorous gases: Sources and abatement technologies. In: *Animal manure recycling: Treatment and management*, S.G. Sommer, M.L. Christensen, T. Schmidt, L.S. Jensen, (eds). John Wiley & Sons, Chichester, UK, 153 pp.
- Galassi G.S., Colombini L., Malagutti G., Crovetto A., Rapetti L. (2010). Effects of high fibre and low protein diets on performance, digestibility, nitrogen excretion and ammonia emission in the heavy pig. *Anim. Feed Sci. Technol.*, 161: 140–148.
- Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A., Tempio G. (2013). Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.
- Grela E.R., Kowalczyk-Pecka D., Hanczakowska E., Matras J. (2016). Effect of inulin and a probiotic supplement in the diet of pigs on selected traits of the gastrointestinal microbiome. *Med. Weter.*, 72: 448–452.
- Guarino M., Fabbri C., Navarotto P., Valli L., Mascatelli G., Rossetti M., Mazzotta V. (2003). Ammonia, methane and nitrous oxide emissions and particulate matter concentrations in two different buildings for fattening pig. In: *Proceedings of the International Symposium on Gaseous and Odour Emissions from Animal Production Facilities*, Commission Internationale de Génie Rural (ed.). Danish Institute for Agricultural Sciences Foulum, Denmark, pp. 140–149.
- Guingand N., Quiniou N., Courboulay V. (2010). Comparison of ammonia and greenhouse gas emissions from fattening pigs kept either on partially slatted floor in cold conditions or on fully slatted floor in thermoneutral conditions. *J. Rech. Porcine*, 42: 277–284.
- Gungor K., Alkan-Ozkaynak A., Karthikeyan K.G., Evrendilek F., Gunasekaran S. (2016). Modeling of solubilization dynamics of manure organic matter and phosphorus as a function of pH control and enzyme supplementation. *Environ. Protect. Eng.*, 42: 155–170.
- Hansen M.J., Jonassen K.E.N., Lokke M.M., Adamsen A.P.S., Feilberg A. (2016). Multivariate prediction of odor from pig production based on in-situ measurement of odorants. *Atmos. Environ.*, 135: 50–58.

- Hansen M.J., Kamp J.N., Adamsen A.P.S., Feilberg A. (2020). Low-emission slurry pits for pig houses with straw application. *Biosyst. Eng.*, 197: 56–63.
- Hayes E.T., Curran T.P., Dodd V.A. (2006). Odour and ammonia emissions from intensive pig units in Ireland. *Bioresour. Technol.*, 97: 940–948.
- Herrero M., Thornton P.K. (2013). Livestock and global change: emerging issues for sustainable food systems. *Proc. Natl. Acad. Sci. USA.*, 110: 20878–20881.
- Institute of Public Health and Environmental, 2004.
- IPCC. Guidelines for National Greenhouse Gas Inventories (2006). Available online: www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html
- IPPC Directive – Integrated Pollution Prevention and Control – consolidated text, Official Journal of the EU L 24 of 29.01.2008.
- IPPC Directive (2008) – consolidated text, Official Journal of the EU L 24 of 29.01.2008.
- Janus M., Więcek J., Pietkiewicz S. (2016). Pig housing system versus greenhouse gas emissions. *Anim. Sci.*, 55: 31–37.
- Jiang T., Schuchardt F., Li G.X., Guo R., Zhao Y.Q. (2011). Effect of C/N ratio, aeration rate and moisture content on ammonia and greenhouse gas emission during the composting. *J. Environ. Sci.*, 23: 1754–1760.
- Journal of Laws 2010 no. 213 item 1397. Regulation of the Council of Ministers of November 9, 2010 on projects that may have a significant impact on the environment.
- Journal of Laws of 2007 no. 147 item 1033. Act on fertilizers and fertilization.
- Kai P., Pedersen P., Jensen J.E., Hansen M.N., Sommer S.G. (2008). A whole-farm assessment of the efficacy of slurry acidification in reducing ammonia emission. *Eur. J. Agron.*, 28: 148–154.
- Kavolielis B. (2006). Impact of animal housing systems on ammonia emission rates. *Polish J. Environ. Stud.*, 15: 739–745.
- Koger J.B., O'Brien B.K., Burnette R.P., Kai P., van Kempen M.H.J.G., van Heugten E., van Kempen T.A.T.G. (2014). Manure belts for harvesting urine and feces separately and improving air quality in swine facilities. *Livest. Sci.*, 162: 214–222.
- Korczyński M., Opaliński S., Kołacz R., Dobrzański Z., Gbiorczyk W., Szotłysik M. (2010). Chemical and biotechnological preparations for litter, manure and slurry limiting the emission of odors and toxic gases “at source”. *Contemporary odor issues. Scientific and Technical Publishing House, Warsaw.*
- Landrain B., Ramonet Y., Quillien J.P., Robin P. (2009). Impact of the installation of a V-shaped scraper under slats in a fattening piggery on performances et on ammonia and nitrous oxide emissions. *J. Rech. Porc.*, 41: 259–264.
- Lindberg J.E. (2014). Fiber effects in nutrition and gut health in pigs. *J. Anim. Sci. Biotechnol.*, 5: 5–15.
- Liu D., Feilberga A., Adamsena A.P.S., Jonassen K.E.N. (2011). The effect of slurry treatment including ozonation on odorant reduction measured by in-situ PTR-MS. *Atmos. Environ.*, 45: 3786–3793.
- Maeda K., Hanajima D., Toyoda S., Yoshida N., Morioka R., Osada T. (2011). Microbiology of nitrogen cycle in animal manure compost. *Microb. Biotechnol.*, 4: 700–709.
- Marszałek M., Kowalski Z., Makara A. (2018). Emission of greenhouse gases and odorants from pig slurry – effect on the environment and methods of its reduction. *Ecol. Chem. Eng. S.*, 25: 383–394.
- Matusiak K., Gutarowska B., Borowski S. (2013). Characteristics of microorganisms capable of removing odor volatile compounds from chicken droppings. *Woda Środ. Obsz. Wiej.*, 13: 89–101.
- Mielcarek-Bocheńska P., Rzeźnik W. (2015). Odor emission factors from livestock production. *Polish J. Environ. Stud.*, 24: 27–35.
- Misselbrook T., Hunt J., Perazzolo F., Provolo G. (2016). Greenhouse gas and ammonia emissions from slurry storage: impacts of temperature and potential mitigation through covering (pig slurry) or acidification (cattle slurry). *J Environ. Qual.*, 45: 1520–1530.
- Moehn S., Bertolo R., Pencharz P., Ball R. (2004). Pattern of carbon dioxide production and retention is similar in adult pigs when fed hourly, but not when fed a single meal. *BMC Physiol.*, 4: 4–11.

- Mohajan H.K. (2012). Dangerous effects of methane gas in atmosphere. *Internat. J. Econom. Political Integrat.*, 2: 3–10.
- Monteiro D.O., Pinheiro V.M.C., Medeiros M.J.L., Machado R.M.A. (2010). Strategies for mitigation of nitrogen environmental impact from swine production. *Rev. Bras. Zootecn.*, 39 (Suppl.): 317–325.
- Mostafa E., Selders A., Gates R.S. (2020). Pig barns ammonia and greenhouse gas emission mitigation by slurry aeration and acid scrubber. *Environ. Sci. Pollut. Res.*, 27: 9444–9453.
- Mroczek J.R. (2009). The use of *Yucca schidigera* extract in fattening pigs. *Pol. Tow. Inż. Ekol.*, 11: 171.
- Naseem S., King A.J. (2018). Ammonia production in poultry houses can affect health of humans, birds, and the environment—techniques for its reduction during poultry production. *Environ. Sci. Pollut. Res.*, 25: 15269–15293.
- Nowakowicz-Dębek B., Wlazło Ł., Stasińska B., Kułczyński M., Ossowski M., Krzaczek P., Bis-Wencel H. (2017). Emission of methane from intensive pig breeding. *Przem. Chem.*, 96: 2353–2357.
- Oleksy M., Dobrzański Z., Matusiak Z., Borowski K., Korczyński M., Gutrowska B. (2015). Physicochemical and biological methods of deodorization. Theoretical and practical aspects. *Przem. Chem.*, 1: 213–217.
- Opaliński S., Korczyński M., Szoltyś M., Kołacz R., Dobrzański Z., Gbiorczyk W. (2010). Application of mineral sorbents to filtration of air contaminated by odorous compounds. *Chem. Enging. Transact.*, 23: 369–374.
- Orzi V., Riva C., Scaglia B., D'Imporzano G., Tambone F., Adani F. (2018). Anaerobic digestion coupled with digestate injection reduced odour emissions from soil during manure distribution. *Sci. Total Environ.*, 621: 168–176.
- Osada T., Rom H.B., Dahl P. (1998). Continuous measurement of nitrous oxide and methane emission in pig units by infrared photoacoustic detection. *Trans. ASAE*, 41: 1109–1114.
- Papatsiros V.G., Billinis C. (2012). The prophylactic use of acidifiers as antibacterial agents in swine. In: *Antimicrobial agents*, V. Bobbarala (ed.). InTech, Rijeka, Croatia 295.
- Petersen S., Andersen A., Jørgen E. (2012). Effects of cattle slurry acidification on ammonia and methane evolution during storage. *J. Environ. Qual.*, 41: 88–94.
- Pezzuolo A., Sartori C., Vigato E., Guercini S. (2019). Effect of litter treatment with probiotic bacteria on ammonia reduction in commercial broiler farm. *Eng. Rural Dev.*, 22–24: 1631–1635.
- Philippe F.X., Nicks B. (2014). Review on greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. *Agric. Ecosyst. Environ.*, 199: e10–e25.
- Philippe F., Nicks B. (2015). Review on greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. *Agric. Ecosyst. Environ.*, 199: 10–25.
- Philippe F., Cabaraux J., Nicks B. (2011). Ammonia emissions from pig houses: Influencing factors and mitigation techniques. *Agric. Ecos. Environ.*, 141: 245–260.
- Pierce K.M., Callan J.J., McCarthy P., O'Doherty J.V. (2005). Performance of weanling pigs offered low or high lactose diets supplemented with avilamycin or inulin. *Anim. Sci.*, 80: 313–318.
- Recharla N., Kim K., Park J., Jeong I., Jeong Y., Lee H., Hwang O., Ryu J., Baek Y., Oh Y., Park S. (2017). Effects of amino acid composition in pig diet on odorous compounds and microbial characteristics of swine excreta. *J. Anim. Sci. Technol.*, 59: 28–36.
- Roberfroid M., Gibson G.R., Hoyles L., McCartney A.L., Rastall R., Rowland I., Wolvers D., Watzl B., Szajewska H., Stahl B., Guarner F., Respondek F., Whelan K., Coxam V., Davicco M.J., Léotoing L., Wittrant Y., Delzenne N.M., Cani P.D., Neyrinck A.M., Meheust A. (2016). Prebiotic effects: metabolic and health benefits. *Br. J. Nutr.*, 104: 1–63.
- Rodriguez M.R., Losada E., Besteiro R., Arango T., Velo R., Ortega J.A., Fernandez M.D. (2020). Evolution of NH_3 concentrations in weaner pig buildings based on setpoint temperature. *Agronomy*, 10: 107–114.

- Rütting T., Aronsson H., Delin S. (2018). Efficient use of nitrogen in agriculture. *Nutr. Cycl. Agroecosyst.*, 110: 1–5.
- Saeed M., Arain M.A., Naveed M., Alagawany M., El-Hack M.E.A., Bhutto Z.A., Chao S. (2018). *Yucca schidigera* can mitigate ammonia emissions from manure and promote poultry health and production. *Environ. Sci. Pollut. Res.*, 25: 1–7.
- Sajeev E.P.M., Winiwarter W., Amon B. (2017). Greenhouse gas and ammonia emissions from different stages of liquid manure management chains: Abatement options and emission interactions. *J. Environ. Qual.*, 30: 30–40.
- Sapek A. (2013). Non-agricultural sources of ammonia emissions to the atmosphere. *Woda Środ. Obsz. Wiej.*, 13: 95–110.
- Sommer S.G., Zhang G.Q., Bannink A., Chadwic D., Misselbrook T., Harrison R., Hutchings N.J., Menzi H., Monteny G.J., Ni J.Q., Oenema O., Webb J. (2006). Algorithms determining ammonia emission from buildings housing cattle and pigs and from manure stores. *Adv. Agron.*, 89: 261–335.
- Sun G., Guo H.Q., Peterson J., Predicala B., Lague C. (2008). Diurnal odor, ammonia, hydrogen sulfide, and carbon dioxide emission profiles of confined swine grower/finisher rooms. *J. Air Waste Manage. Assoc.*, 58: 1434–1448.
- Swamy Y.V., Venkanna R., Nikhil G.N., Chitanya D.N.S.K., Sinha P.R., Ramakrishna M., Rao A.G. (2012). Impact of nitrogen oxides, volatile organic compounds and black carbon on atmospheric ozone levels at a semiarid urban site in Hyderabad. *Aerosol Air Qual. Res.*, 12: 662–671.
- Syp A. (2017). Greenhouse gas emissions from agriculture between 1990 and 2014. *Problems of World Agriculture*, 17: 244–255.
- Tako E., Glahn R.P., Welch R.M., Lei X., Yasuda K., Miller D.D. (2008). Dietary inulin affects the expression of intestinal enterocyte iron transporters, receptors and storage protein and alters the microbiota in the pig intestine. *Brit. J. Nutr.*, 99: 478–480.
- Tymczyna L., Chmielowiec-Korzeniowska A., Drabik A. (2009). Effect of pig confinement housing system on emission of gaseous air pollutants. *Przem. Chem.*, 88: 574–578.
- Tymczyna L., Chmielowiec-Korzeniowska A., Drabik A., Raczyńska J. (2010). Biofiltration of volatile organic compounds (VOC) in the exhaust air of a fattening house. *Przem. Chem.*, 89: 567–573.
- Valenzuela-Grijalva N.V., Pinelli-Saavedra A., Muhlia-Almazan A., Domínguez-Díaz D., González-Ríos H. (2017). Dietary inclusion effects of phytochemicals as growth promoters in animal production. *J. Anim. Sci. Technol.*, 59: 1–17.
- Van De Wiele T., Boon N., Possemiers S., Jacobs H., Verstraete W. (2007). Inulin-type fructans of longer degree of polymerization exert more pronounced *in vitro* prebiotic effects. *J. Appl. Microbiol.*, 102: 452–460.
- Van Der Heyden C., Demeyer P., Volcke E.I. (2015). Mitigating emissions from pig and poultry housing facilities through air scrubbers and biofilters: State-of-the-art and perspectives. *Biosys. Eng.*, 134: 74–93.
- Walczak J. (2017). The importance of zootechnical sciences in environmental protection and combating climate change. National results of research and assessment activities in the field of environmental protection and climate change in the agriculture sector. National Research Institute of Animal Production, Kraków.
- Wang K., Wei B., Zhu S., Ye Z. (2011). Ammonia and odour emitted from deep litter and fully slatted floor systems for growing-fattening pigs. *Biosys. Enging.*, 109: 203–210.
- Wang K., Huang D., Ying H., Luo H. (2014). Effects of acidification during storage on emissions of methane, ammonia, and hydrogen sulfide from digested pig slurry. *Biosyst. Eng.*, 122: 23–30.
- Wang Y., Li X., Yang J., Tian Z., Sun Q., Xue W., Dong H. (2018). Mitigating greenhouse gas and ammonia emissions from beef cattle feedlot production: A system meta-analysis. *Environ. Sci. Technol.*, 52: 11232–11242.
- Webb J., Pain B., Bittman S., Morgan J. (2010). The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response – a review. *Agric. Ecos. Environ.*, 137: 39–46.

- Webb J., Broomfield M., Jones B.S., Donovan B. (2014). Ammonia and odour emissions from UK pig farms and nitrogen leaching from outdoor pig production. A review. *Sci. Total Environ.*, 470: 865–875.
- Zhang Z.F., Kim I.H. (2014). Effects of multistrain probiotics on growth performance, apparent ileal nutrient digestibility, blood characteristics, cecal microbial shedding, and excreta odor contents in broilers. *Poultry Sci.*, 93: 364–370.
- Ziemann P.J., Atkinson R. (2012). Kinetics, products, and mechanisms of secondary organic aerosol formation. *Chem. Soc. Rev.*, 41: 6582–6605.
- Zong C., Li H., Zhang G. (2015). Ammonia and greenhouse gas emissions from fattening pig house with two types of partial pit ventilation systems. *Agric. Ecosyst. Environ.*, 208: 94–105.

Received: 7 IX 2020

Accepted: 19 II 2021