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REVIEW

Nutritional approaches to reduce ammonia and odorous compounds from pig manure

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ABSTRACT. Emissions of ammonia and odorous compounds from pig manure have attracted attention due to their negative effects on the environment and public health. Ammonia from the pig urine is one of the major environmental contaminants. Odorous compounds produced by microbial action on the organic matter in manure include volatile fatty acids, phenolic compounds, indole compounds, and hydrogen sulphide. The odorous compounds are primarily attributed to the dietary nutrient composition, gastrointestinal environment of pigs, and chemical reactions in the slurry. Several nutritional approaches used to mitigate the ammonia emissions are available. The first method involves reducing nitrogen excretion by lowering dietary crude protein concentrations and using digestive enzymes to improve protein digestibility and utilization in pigs. The second method involves supplementing diets with acidifying agents, such as benzoic acid or adipic acid, or lowering the dietary electrolyte balance to acidify the slurry. Finally, supplementation with materials containing urease inhibitor, such as *Yucca schidigera* extract and humic substances can inhibit urease activation in pig manure. Methods for reducing odorous compounds have also been suggested. Reducing undigested protein in pig manure is known to reduce odorous compounds. Selected feed additives may also function either by providing a terminal electrolyte acceptor for bacteria or by reducing the population of intestinal bacteria that produce odorous compounds in pig manure. Based on the present review, however, nutritional approaches for reducing odorous compounds in pig manure are not entirely convincing. Further research is required to investigate effective ways to reduce odorous compounds in pig manure.

Introduction

Ammonia gas and odorous compounds negatively impact the environment and public health including pig house neighbours and workers (Seo et al., 2023; Choi et al., 2024). Neighbours who experienced odours produced from a pig farm were reported to have high levels of tension, depression, anger, and confusion (Schiffman et al., 1995). In addition, Thu et al. (1997) observed symptoms of toxicity and inflammation in the respiratory tracts in the neighbours living near a pig farm. To address these issues, the emissions of ammonia gas and odorous compounds including volatile fatty acids (VFA) and volatile organic compounds from pig production have been widely studied.

Ammonia gas is produced in pig slurry via the hydrolysis of urea by the action of urease (Tabase et al., 2023). The emission of ammonia gas leads to the formation of fine particulates and eutrophication of ecosystems, contributing to global climate change as identified in several studies (Charlson et al., 1990;

Krupa, 2003; Bauer et al., 2007; Myhre et al., 2009). The decrease in pig productivity is also considered serious problem in swine industry (Headon and Walsh, 1994). Odorous compounds are generated by the microbial fermentation of undigested nutrients and endogenous components in the pig slurry during storage in a slurry pit (Hwang et al., 2016). These odorous compounds have raised serious concerns about air pollution and human health issues such as respiratory diseases (Cole et al., 2000). The production of ammonia gas and odorous compounds is primarily attributed to the dietary nutrient composition, gastrointestinal environment of pigs, and chemical reactions occurring in the slurry. Several nutritional approaches have been adopted to mitigate the emissions of ammonia and odorous compounds (Eriksen et al., 2010; Philippe et al., 2011; Upadhaya et al., 2014).

Three nutritional approaches have been suggested in previous studies to reduce ammonia excretion. The first approach is to reduce nitrogen (N) excretion from pigs by lowering dietary N contents or improving protein utilization through addition of feed additives (Kerr and Easter, 1995; Le Bellego et al., 2001; Galassi et al., 2010). The second is adding acidifying agents to pig diets or lowering the dietary electrolyte balance to induce acidic conditions in pig manure (Canh et al., 1998; Bühler et al., 2006; Sauer et al., 2009; Eriksen et al., 2010; Murphy et al., 2011; Choi and Kim, 2024). Finally, urease inhibitors that is not digested by pigs can be used to reduce production of ammonia gas by inhibiting urease activation in pig manure (Colina et al., 2001; Hong et al., 2001; Ji et al., 2006; Panetta et al., 2006). Potential approaches to reduce odorous compounds include reducing excreted nutrients by lowering dietary nutrient concentrations, such as crude protein, and supplementing pig diets with feed additives that inhibit bacterial growth or promote nutrient degradation in pig intestines (Halas et al., 2010; Upadhaya et al., 2014; Yoo et al., 2024a; Yoo et al., 2024b). In this paper, the mechanisms of ammonia gas and odorous compound production are reviewed, along with nutritional approaches for reducing the malodour emissions from pig manure.

Odour compounds in pig production

In pig production, odorous compounds generally originate from pig faeces and urine. Pig faeces contain undigested nutrient compounds, including endogenous components, digestive enzymes, and intestinal microbiota (Zhu and Jacobson, 1999; Vhile et al., 2012). In pig urine, urea is excreted with an abundance of moisture. Under practical conditions, faeces and urine are mixed to form manure, which is then stored in a pit or a lagoon depending on the types of pig production. Typically, pig manure is stored under anaerobic conditions with a high moisture content, providing a suitable environment for microbial activation (Miller and Varel, 2003). Consequently, ammonia gas and odorous compounds are produced by the microbial fermentation of protein and fermentable carbohydrates in pig manure during storage in the slurry pit. The processes of ammonia gas volatilization and formation of odorous compounds in pig manure are described in this review.

Ammonia

Ammonia gas commonly originates from the mineralization of organic N compounds in pig manure by bacteria to supply energy for bacterial growth (Philippe et al., 2011). As ingested N from commercial feed ingredients is not fully utilized in the pig body, unabsorbed and unutilized N is excreted through faeces and urine, respectively. In pig faeces, unabsorbed N from the intestine is excreted in the form of proteins. Due to the low susceptibility of faecal N compounds to rapid decomposition, microbial fermentation is necessary to degrade faecal N compounds into ammonium cations (Zervas and Zijlstra, 2002). In urine, unutilized amino acids in enterocytes are degraded and converted into urea in the liver, which is then excreted via the kidneys. In contrast to faecal N compounds, urea excreted through urine is easily hydrolysed into ammonium cations and bicarbonate, mainly due to its simple structure and rapid degradation by urease (McCrory and Hobbs, 2001). Urease is particularly abundant in pig faeces because faecal microbial groups including *Streptococcus salivarius*, *Actinomyces naeslundii*, and *Lactobacillus reuter* produce this enzyme, leading to the acceleration of ureolysis in pig manure. After ureolysis, the ammonium cation dissociates into ammonia, which is then volatilized into the air (Philippe et al., 2011).

Ammonia gas emitted into the air can cause respiratory illnesses in animals due to its noxious characteristics (Headon and Walsh, 1994). In addition, ammonia gas can attach to fine dust produced in the inside of pig houses, which may induce the impaired function of respiratory system (Kafle and Chen, 2014). Therefore, long-term exposure to high concentrations of aerial ammonia gas in housing can adversely affect the productivity of pigs (Stombaugh et al., 1969) and the public health of neighbours and workers in pig houses (Preller et al., 1995; Kim et al., 2008a,b). Therefore, regulation of ammonia production is emphasized (Kim et al., 2008b; Philippe et al., 2011).

Odorous compound formation

Odorous compounds are the end products of fermentable carbohydrates and undigested amino acids in the large intestine. The main components of odorous compounds include VFA, indole, phenol, and volatile sulphur-containing compounds (Zhu and Jacobson, 1999). Volatile fatty acids are produced by the fermentation of carbohydrates and branched-chain amino acids in the large intestine. The VFA include acetic, propionic, and butyric acids, which are produced during carbohydrate fermentation, and isobutyric, valeric, and isovaleric acids, that are produced by the deamination of branched-chain amino acids in the large intestine. The bacterial genera involved in VFA production include *Eubacterium*, *Peptostreptococcus*, *Bacteroides*, *Streptococcus*, *Escherichia*, *Megasphaera*, *Propionibacterium*, *Lactobacilli*, and *Clostridium*. Phenolic compounds, including phenol and *p*-Cresol, are produced by the microbial degradation of tyrosine and phenylalanine in the intestine. Tryptophan is degraded into indole or indole-3-acetate which is subsequently converted into skatole by different bacterial groups. The bacterial genera involved in the production of indole and phenol compounds include *Propionibacterium*, *Escherichia*, *Eubacterium*, and *Clostridium*. Volatile sulphur-containing compounds include methyl- and ethyl-mercaptans, which are derived from sulphur-containing compounds such as sulphur-containing amino acids or result from the process of sulphate elimination within the cell. *Megasphaera* is a bacterial genus involved in the production of volatile sulphur-containing compounds. The bacterial genera that produce specific odorous compounds and the precursors, as identified by Zhu and Jacobson (1999), Williams et al. (2001), and Vhile et al. (2012), are listed in Table 1.

The composition and quantity of odorous compounds in pig manure vary depending on the nutrients in the feeds and the bacterial genera inhabiting pigs. Therefore, odorous compounds can be regulated by the dietary composition and storage conditions of pig manure, such as temperature and pH, which can influence bacterial populations (Sutton et al., 1999; Zhu and Jacobson, 1999). However, studies on nutritional methods for reducing odorous compounds in pig manure are scarce due to the difficulty of measurement and the requirement for specialized equipment. Further research is warranted to address this issue.

Table 1. List of odorous compounds, precursors, and bacterial genera[1]

Type of odorous compounds	Composition	Precursor	Bacterial genera
Volatile fatty acids	Acetic, propionic, butyric acid	Fermentable carbohydrate	*Eubacterium, Peptostreptococcus, Bacteroides, Streptococcus, Escherichia, Megasphaera, Propionibacterium, Lactobacilli, Clostridium*
	Isobutyric, isovaleric, valeric acid	Branched-chain amino acid	
Indole compounds	Indole, skatole	Tryptophan	*Propionibacterium, Escherichia, Eubacterium, Clostridium*
Phenol compounds	Phenol, *p*-cresol	Tyrosine, phenylalanine	
Volatile sulphur-containing compounds	Methyl-, ethyl-mercaptans	Sulphate, sulphur-containing amino acids	*Megasphaera*

[1] adapted from Zhu and Jacobson (1999), Williams et al. (2001), and Vhile et al. (2012)

Nutritional methods for reducing ammonia gas and odorous compounds

To mitigate the emission of ammonia gas and odorous compounds from pig manure, previous studies have investigated several nutritional approaches (Tables 2 and 3): 1) reducing excreted N by lowering dietary protein concentration or improving protein absorption and utilization in pigs, 2) adding acidifier agents to diets to induce acidic slurry conditions, and 3) supplementing diets with a urease inhibitor that is undigested by pigs to inhibit the activation of urease in pig manure.

Reducing nitrogen excretion

As ammonia gas is attributed to faecal and urinary N excretion, ammonia emissions can be reduced by lowering dietary protein concentration or improving N utilization to reduce N excretion. It is natural that reduced protein consumption by excluding protein ingredients such as soybean meal from pig diets leads to a decrease in N excretion. However, reducing the inclusion of protein ingredients also results in a deficiency of essential amino acids for pig growth. Therefore, supplementation of low-protein diets with crystalline amino acids is necessary to meet the amino acid requirements of pigs. In the literature, the reduction of N excretion

Table 2. Effects of supplemental additives on the urinary pH, ammonia gas release, and nitrogen (N) utilization in pigs

Types of additives	Additives	Dose, %	Initial body weight, kg	Number of observations	Urinary pH: Control	Urinary pH: Acidifier treatment	Response	Reference
Proteolytic enzymes	Bromelain	0.05, 0.1, 0.2	6.75	7			A linear decrease in ammonia gas release from manure	Hossain et al. (2015)
		0.03	22.6	9			A 7.1% decrease in faecal ammonia gas release	Nguyen et al. (2018)
			49.6	9			No effects on the ammonia gas release	
			79.8	9				
	Protease	0.02	22.6	9			A 7.0% decrease in faecal ammonia gas release	
			49.6	9			No effects on the ammonia gas release	
			79.8	9				
Acidifying agents	Adipic acid	1.0	25.0	7	7.70	5.50	A 25.0% decrease in ammonia gas release from manure	van Kempen (2001)
		1.0	37.9	6	8.61	7.17	A tendency for a 13.4% decrease in retained N	Yoo et al. (2024a)
	Benzoic acid	0.25, 0.35, 0.50	6.9	9	7.5	6.10, 6.40, 5.70		Choi et al. (2023)
		0.5, 1.0	7.5	6	7.45	6.87, 6.42	A 12.7% decrease in average daily gain	Kluge et al. (2006)
		1.0	26.0	8	7.77	6.76	A 4.1% increase in N digestibility	Bühler et al. (2006)
			56.4	8	7.77	6.71	No effects on N digestibility	
		1.0, 2.0	26.5	6	7.32	6.55, 5.32		Sauer et al. (2009)
		1.0 (Top dressing)	50.0	4	7.01	4.99		Kristensen et al. (2009)
		0.5, 1.0, 1.5, 2.0, 2.5	56.2	8	8.61	8.55, 8.26, 7.44, 6.77, 6.44	A linear increase in N digestibility and a tendency for an increase in digested N	Yoo et al. (2024b)
	Calcium chloride	2.2	40.0	5	6.81	5.17	A 33.0% decrease in ammonia gas release from manure	Canh et al. (1998)
	Calcium sulphate	2.4		5		5.36	A 30.0% decrease in ammonia gas release	
Urease inhibitors	Humic substances	0.5	22.1	16			A tendency for a 18.1% decrease in ammonia gas release from manure	Ji et al. (2006)
	Yucca schidigera extract	0.0125	4.73	3			A tendency for a decrease in ammonia gas release from manure during the 0 to 4 weeks	Colina et al. (2001)
		0.015	77.7	9			A 36.3% decrease in ammonia gas release from manure	Hong et al. (2001)
		0.625, 1.250	41.0	6			No effects on the ammonia gas release	Panetta et al. (2006)

in pigs by lowering dietary crude protein has been demonstrated (Kerr and Easter, 1995; Le Bellego et al., 2001; Galassi et al., 2010). Kerr and Easter (1995) reported an 8.5% decrease in faecal N excretion and a 47.0% decrease in urinary N excretion in pigs fed a low-protein diet supplemented with crystalline amino acids. Le Bellego et al. (2001) observed a 21.7% decrease in faecal N excretion and a 64.8% decrease in urinary N excretion when the dietary protein concentration was reduced from 18.9 to 12.3%; however, no adverse effects on N retention were observed.

In pig faeces, N is present in the form of undigested proteins and other N compounds that are consequently degraded into ammonium by microbial fermentation (McCrory and Hobbs, 2001). Therefore, improving protein digestibility can reduce faecal N excretion in pigs. Supplementing pigs with proteases increases protein digestion and N absorption and consequently reduces ammonia emissions (Hossain et al., 2015; Nguyen et al., 2018). In a previous study, a 7 or 7.1% decrease in faecal ammonia gas emissions was observed compared with the control group during the nursery phase,

Table 3. Methods for reducing odorous compounds in pigs

Methods	Initial body weight, kg	Number of observations	Treatment	Response	Reference
Reducing dietary crude protein composition	35.0	3	Reduced dietary crude protein from 21 to 14%	Decreases in acetic acid, propionic acid, isovaleric acid, phenol, indole, and skatole in slurry	Hobbs et al. (1996)
	65.0	3	Reduced dietary crude protein from 19 to 13%	Decreases in acetic acid, propionic acid, butyric acid, isovaleric acid, valeric acid, *p*-cresol, phenol, indole, and skatole in slurry	
	36.5	6	Reduced dietary crude protein from 18 to 12%	Decreases in acetic acid, propionic acid, butyric acid, isobutyric acid, isovaleric acid, phenol, and indole in manure	Le et al. (2007)
	41.4	4	Reduced dietary crude protein from 19 to 14%	Linear decreases in hydrogen sulphide and ammonia gas release from manure	Niyonsaba et al. (2023)
	45.0	10	Reduced dietary crude protein from 18 to 13%	A linear decrease in skatole in slurry	Ball et al. (2022)
	57.7	6	Reduced dietary crude protein from 15 to 12%	Decreases in acetic acid, propionic acid, isobutyric acid, isovaleric acid, phenol, indole, and ammonia in manure	Le et al. (2009)
Supplementing additives	5.9	6	Supplement with 0.5% benzoic acid	Decreases in butyric acid, valeric acid, isovaleric acid	Halas et al. (2010)
	22.6	5	Supplement with 0.1% organic acid blends	A 20.3% decrease in hydrogen sulfide in manure	Upadhaya et al. (2014)
	37.9	6	Supplement with 1.0% humic substances	A tendency for a 56.3% decrease in indole slurry and a tendency for a 25.3% decrease of isovaleric acid in faeces	Yoo et al. (2024a)
	56.2	8	Supplement with 0.5 to 2.5% benzoic acid	Linear decreases in acetic acid, propionic acid, butyric acid, isovaleric acid, and skatole in faeces and slurry	Yoo et al. (2024b)

when pigs were fed diets supplemented with 0.02% protease or 0.03% bromelain, respectively (Nguyen et al., 2018). However, the effects of supplemental protease or bromelain on faecal ammonia gas emissions were not observed in growing and finishing pigs (Nguyen et al., 2018) likely due to their greater protein digestibility than that of nursery pigs. In addition, supplementary bromelain decreased ammonia gas emissions from pig manure in a dose-dependent manner (Hossain et al., 2015).

Odorous compounds can be reduced by decreasing dietary N because odorous compounds are primarily produced by microbial fermentation of undigested nutrients in pig manure. Hobbs et al. (1996) reported that lowering dietary crude protein concentrations resulted in reduced odorous compounds in pig slurry. Additionally, Niyonsaba et al. (2023) reported that pigs fed diets with crude protein reduced from 19.0 to 14.0% showed a linear decrease in hydrogen sulphide emissions from pig manure. These studies indicate that odorous compound concentrations can be reduced by modifying the nutrient composition of pig diets.

Taken together, ammonia and odorous compound emissions from pig production are mainly dependent on N excretion from pigs. A decrease in dietary N concentrations apparently reduces N excretion from pigs by reducing N intake. In addition, protein-degrading enzymes can also be considered to reduce ammonia and odorous compound emissions from pigs. However, further research is needed to clarify the effects of protease and bromelain on gas emissions.

Acidifying agents

Both urease activation and dissociation of ammonium cations are inhibited by the acidic conditions of pig manure. Therefore, supplementing pig diets with acidifying agents could regulate the volatilization of ammonia gas from urine. Kim et al. (2022) reported that the amount of N in urine remained constant with no effect of time, despite exposure to air, when 6 N hydrochloride acid was added to urine. Regarding the nutritional methods for inducing acidic conditions in urine, the effects of several acidifying agents on urinary pH have been reported.

Benzoic acid (BA) is the simplest form of an aromatic carboxylic acid and consists of a benzene ring with a carboxyl substituent (Choi and Kim, 2024). When ingested by pigs, BA is rapidly absorbed and conjugated to glycine in the liver. Consequently, BA is converted into hippuric acid and then excreted via urine, lowering the urinary pH (Bühler et al., 2006; Kristensen et al., 2009; Eriksen et al., 2010; Choi et al., 2023). Kristensen et al. (2009) reported that adding 1.0% BA to pig diets reduced the urinary pH from 7.01 to 4.99. Additionally, Sauer et al. (2009) and Murphy et al. (2011) reported linear and quadratic decreases in urinary pH, respectively, in pigs fed diets supplemented with increasing amounts of BA. A reduction in the ammonia emitted from pig manure has been suggested in previous studies (Kim et al., 2008c; Eriksen et al., 2010; Murphy et al., 2011; Kim et al., 2025). However, the effects of BA on urinary pH have been inconsistent. Yoo et al. (2024a) reported that urinary pH of pigs fed 1.0% dietary BA did not differ from the control group. This inconsistency may be due to differences in the experimental methods used to collect urine from the pigs. Other previous studies collected urine samples directly from the bladder by sacrificing pigs (Kluge et al., 2006; Choi et al., 2023) or by using equipped catheters (Eriksen et al., 2010; Patráš et al., 2014). In contrast, Yoo et al. (2024a) collected excreted urine daily from pigs into containers. The collection method using containers may have exposed the urine samples to external factors such as air and microbial fermentation, resulting in an increase in urine pH. Another possible reason is the potential detrimental effects of BA on the pig liver caused by a long feeding period because the damaged liver may have less ability to convert BA into hippuric acid (Shu et al., 2016). Supplemental BA in diets have been also suggested to reduce N excretion through faeces. In previous studies, pigs fed a diet supplemented with BA showed increased N digestibility and decreased faecal N excretion, which may be attributed to the function of BA in lowering pH in the gastrointestinal tract of pigs (Min et al., 2008; Halas et al., 2010; Diao et al., 2016; Mao et al., 2019; Choi and Kim, 2024; Yoo et al., 2024b).

Adipic acid is a dicarboxylic acid with a 6-carbon chain. When present in excess levels in pig blood, adipic acid is excreted via urine, resulting in acidic urinary pH. van Kempen (2001) reported a 25.0% decrease in ammonia gas emissions when 1% adipic acid was added to pig diets, which resulted in a reduction of urinary pH from 7.7 to 5.5. Yoo et al. (2024a) also reported that urinary pH of pigs fed 1.0% dietary adipic acid decreased from 8.61 to 7.17.

Reducing the dietary electrolyte balance can also be used to reduce urinary pH. The dietary electrolyte balance represents the ratio of cations to anions in a pig diet and determines the acid-base status of pigs (Patience et al., 1987). When pigs are fed a low-electrolyte balanced diet, urinary excretion of hydrogen increases, leading to a lower urinary pH (Bournazel et al., 2020). To reduce the dietary electrolyte balance, calcium sulphate and calcium chloride, which are often considered acidifying agents that induce urinary net acid excretion (Canh et al., 1998), have been suggested to decrease the urinary pH in pigs. Canh et al. (1998) reported that the inclusion of 2.2% calcium chloride and 2.4% calcium sulphate in growing pig diets to replace calcium carbonate reduced the urinary pH from 6.81 to 5.17 and 5.36, resulting in 33.0% and 30.0% reductions in ammonia emissions, respectively.

Supplemental BA can also reduce odorous compounds in pig manure due to its positive effects on intestinal microbial populations (Kluge et al., 2006). Halas et al. (2010) reported that adding 0.5% BA to pig diets reduced odorous compound concentrations such as butyrate and isovalerate in caecal digesta. Yoo et al. (2024b) also reported that pigs fed with increased dietary BA from 0.5 to 2.5% showed a linear decrease in acetate, propionate, butyrate, and skatole concentrations in faeces and slurry. Benzoic acid is known to exert oxidative stress on bacteria that produce odorous compounds in pig intestines (Hazan et al., 2004; Choi and Kim, 2024). Similarly, dietary organic acids have also been reported to reduce odorous compounds in pig manure by suppressing bacterial growth due to decreased intestinal pH. Upadhaya et al. (2014) observed that hydrogen sulphide concentration in manure decreased by 20.3% when pigs were fed a diet supplemented with an organic acid blend containing fumaric acid, citric acid, malic acid, and medium-chain fatty acids.

Overall, the acidity of intestinal digesta and manure is one of the critical factors involved in the emissions of odorous compounds and ammonia. Acidifying the intestinal digesta by dietary organic acids reduced odorous compounds from faeces. Lowering urinary pH by dietary BA, adipic acid, calcium sulphate, or calcium chloride reduced ammonia emissions from pig urine. In the future, research to determine optimum electrolyte balance to reduce ammonia emissions is warranted. In addition, potential interactions between dietary N concentration and electrolyte balance would also need to be investigated.

Urease inhibitor

Urease is a key enzyme involved in urea hydrolysis. Once urea is degraded into ammonium, ammonia gas is produced and emitted due to the dissociation of ammonium. In agricultural research, the inhibition of urease activity has been investigated to decrease N loss in soils by preventing urea hydrolysis, which could be a promising method to reduce ammonia emissions. The materials used to deactivate urease include N-(n-butyl) thiophosphoric triamide (Cantarella et al., 2018), boric acid (Benini et al., 2004), humic substances (Liu et al., 2019), and trace minerals (Tabatabai, 1977). On the other hand, feed additives in pig diets, including *Yucca schidigera* extract and humic substances, have been suggested to inactivate urease in pig urine, thereby reducing ammonia emissions.

Yucca schidigera extract, a natural plant product, has been demonstrated to reduce ammonia emissions from pig manure by inhibiting urease activity when supplemented in pig diets (Colina et al., 2001). Hong et al. (2001) reported a 36% reduction in ammonia emissions in pigs fed a diet containing 150 mg/kg *Yucca schidigera* extract. Colina et al. (2001) observed that pigs fed a diet containing 125 mg/kg *Yucca schidigera* extract showed a tendency for ammonia reduction during a 4-week manure storage period. However, Panetta et al. (2006) reported no effects of *Yucca schidigera* extract on ammonia gas emissions from pig manure, which is inconsistent with the results of the aforementioned two studies (Colina et al., 2001; Panetta et al., 2006). The reason for this inconsistency remains unclear because the mechanism of action of *Yucca schidigera* extract is unknown.

Humic substances are organic complexes produced in the soil and consist of humic acid, fulvic acid, and humin. Humic substances have a negative charge and, therefore, capture many trace mineral ions that can affect urease activity (Tabatabai, 1977). Because pigs have a limited ability to completely digest and absorb humic substances (Stevenson, 1994), dietary humic substances can be excreted in pig faeces and contribute to a decrease in urease activity in pig manure. In a study by Ji et al. (2006), ammonia gas emissions in pigs fed a diet supplemented with 0.5% humic substances tended to decrease by 18.1% compared with those in the control group.

Dietary urease inhibitors can also reduce odorous compounds in pig manure. Yoo et al. (2024a) observed that pigs fed a diet including 1.0% humic substances tended to have reduced concentrations of isovalerate in faeces and indole in slurry. Humic substances are utilized by microorganisms as terminal electron acceptors under anaerobic conditions, resulting in further decomposition of the substrates in pig manure (Benz et al., 1998). However, studies on the efficacy of supplemental additives in reducing odorous compounds are limited. Therefore, further research is warranted to clarify the effects of feed additives on odorous compounds in pig manure. Overall, the urease inhibitors, *Yucca schidigera* extract and humic substance, reduce ammonia emission from pig manure by protecting the digestion of urea into ammonia molecules. In addition, humic substances potentially reduce odorous compounds from pigs.

Conclusions

Ammonia gas and odorous compounds are produced in pig farms as a result of undigested and unabsorbed nutrients in pig manure being fermented by microbial activity, which can be harmful to the environment and the public health. Ammonia gas release can be mitigated by reducing nitrogen excretion from pigs, inducing acidic conditions in pig manure, or supplementing pig diets with urease inhibitors. Similarly, odorous compound production can be potentially reduced by dietary nutrient modification, providing terminal electron acceptors, or decreasing the population of microorganisms. However, more research is needed to establish methods for reducing odorous compounds.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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