1   **Title Page**

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Abstract: The emission of noxious gases is a significant problem in pig production, as it can lead to poor production, welfare concerns, and environmental pollution. The noxious gases are the gasses emitted from the pig manure that contribute to air pollution. The increased concentration of various harmful gasses can pose health risks to both animals and humans. The major gases produced in the pig farm include methane, hydrogen sulfide, carbon dioxide, ammonia, sulfur dioxide and volatile fatty acids, which are mainly derived from the fermentation of undigested or poorly digested nutrients. Nowadays research has focused on more holistic approaches to obtain a healthy farm environment that helps animal production. The use of probiotics, prebiotics, dietary enzymes, and medicinal plants in animal diets has been explored as a means of reducing harmful gas emissions. This review paper focuses on the harmful gas emissions from pig farm, the mechanisms of gas production, and strategies for reducing these emissions. Additionally, various methods for reducing gas in pigs, including probiotic interventions; prebiotic interventions, dietary enzymes supplementation, and use of medicinal plants and organic acids are discussed. Overall, this paper provides a comprehensive review of the current state of knowledge on reducing noxious gas in pigs and offers valuable insights for pig producers, nutritionists, and researchers working in this area.

Keywords: enzyme, noxious gas emission, medicinal plants, probiotics, prebiotics, reduction method of gas emission

Introduction

In recent decades, livestock production has shifted to large-scale operations with intensive confinement, improved efficiency as well as a large amount of waste. Among other livestock sectors, pig production is an important industry that provides a valuable source of protein for human consumption. In 2022, 114 million metric tons of pork was produced worldwide [1]. As the pig industry grows day by day, waste management is also becoming important because harmful gases emit from manure. Animal manure decomposition is known to produce over 130 distinct gases including ammonia, hydrogen sulfide, carbon dioxide, and sulfur dioxide [2]. Excessive gas production not only affects the health and welfare of pigs but also increases the cost of feed and manure management, as well as the emission of greenhouse gases, such as methane and carbon dioxide, from manure storage and application [2, 3]. These methane, hydrogen sulfide, carbon dioxide, and volatile fatty acids are produced by the fermentation of undigested or poorly digested nutrients by the gut microbiota [4]. These gases in pigs are produced through microbial fermentation in their large intestine. This complex process is

influenced by factors such as diet, gut microbiota activity, and digestive physiology like other non-ruminant [4,5].

Noxious gas production involves enzymatic, microbial, and chemical reactions to convert feed material or organic materials into gases. However, there has been a growing interest in developing proper and effective methods to reduce gas emission in pig farm. One such approach is nutrition regulation, which involves manipulating the pig diet to reduce the production of gas-forming compounds in the large intestine [4]. This can be achieved through strategies such as limiting the intake of fermentable carbohydrates or increasing the intake of non-digestible fibers [6]. Overall, reducing gas emission in pigs is a complex process. One approach that has shown promise is the use of dietary feed additives. These feed additives can include the use of probiotics, prebiotics, dietary enzymes, and medicinal plants. Probiotics refer to living microorganisms that can provide health advantages to the host [7, 8]. Prebiotics are food components that are indigestible to the host but can promote the proliferation and functionality of *Lactobacillus spp.* in the gastrointestinal tract [9-11]. Dietary enzymes can help improve nutrient digestibility and reduce the production of noxious gases [5,12,13]. Medicinal plants can have antimicrobial and anti-inflammatory properties that can help reduce harmful gas emissions [14,15]. This review paper summarizes the current state of research on gas emissions in pig farm, based on a literature review of various studies. Our goal is to promote the development of sustainable and effective strategies for reducing noxious gas emission in pig farm.

Different gas emission from pig manure

Pig manure is a common source of greenhouse gas emissions that can have a significant impact on the environment. There are several types of gases emitted from pig manure, including methane, carbon dioxide, nitrous oxide and these gases can contribute to global warming [3,14,15]. The emissions of gases from pig farm depend on the daily temperature range. During the warmer hours spanning three hours, the recorded emissions were: 5540 g/pig for carbon dioxide, 181 g/pig for ammonia, 9.1 g/pig for methane, and 302 g/pig for nitrous oxide [16].

Methane is a highly potent greenhouse gas, which is responsible for approximately 18% of the total global greenhouse gas emissions originating from the livestock industry [2,16,17]. During the initial two decades following its emission, methane was approximately 80 times more potent than carbon dioxide as a greenhouse gas [17].

3

63 Hydrogen sulfide is produced during the decomposition of organic matter, including manure. In particular, when

64 manure is stored or handled in a confined space or anaerobic conditions, such as in manure storage pits or

65 lagoons, hydrogen sulfide can build up to toxic levels [18-20]. Hydrogen sulfide exposure can be detrimental to

66 the health of pigs. This exposure can also lead to impaired lung functionality, olfactory dysfunction, and

67 subsequent neurological complications [18]. In swine, hydrogen sulfide levels at 20 ppm have been linked to

68 symptoms such as sensitivity to light, reduced appetite, and heightened agitation. Moreover, swine subjected to

69 hydrogen sulfide concentrations between 50-200 ppm have shown signs of vomiting and diarrhea [19].

70 The carbon dioxide emissions from pig houses arise from two primary sources: respiration by pigs and the

71 release of carbon dioxide from manure [2,21]. This gas is produced when organic matter in the manure is broken

72 down by microorganisms [4]. Carbon dioxide emissions from pig manure are not as potent as methane

73 emissions, but they can still contribute to climate change.

74 Nitrous oxide is produced when nitrogen in the manure is broken down by microorganisms [2,16,22,]. Nitrous

75 oxide has a much greater impact on the environment than carbon dioxide [22].

76

77 **Feed additives to reduce gas emission**

78 In recent days, researchers have been focusing on the manipulation of gas emission through different in-feed

79 additives such as probiotics, prebiotics, dietary enzymes, organic acids, and medicinal plants (Figure 1). These

80 feed additives have some other health benefits without any adverse side effects like antibiotics. The effect of

81 feed additives for reducing gas emission in pig diet is shown in Table 1.

82 **Probiotics**

83 In pig farming, probiotics are used as feed supplements to improve animal health, digestion, and growth

84 performance [23-25]. Probiotics, such as *Bacillus amyloliquefaciens*, *Limosilactobacillus reuteri*, and

85 *Levilactobacillus brevis*, are specifically chosen for their ability to restore and maintain the balance of gut

86 microbiota, particularly *Lactobacillus spp.* and *Bifidobacterium spp.* [8,26]. This balance is crucial for optimal

87 gut health but can be disrupted due to various factors like stress, disease, and dietary changes [27,23]. This play

88 a vital role in enhancing the digestion of feed, thereby ensuring efficient nutrient uptake and reducing the

89 incidence of gastrointestinal diseases.

90   Probiotics such as *B. amyloliquefaciens*, *L. reuteri*, and *L. brevis* improve the gut health and digestion of feed,

91   which reduces the amount of undigested organic matter in manure and decrease the production of methane and

92   other gases during manure decomposition [8,26,28]. Additionally, probiotics can help the proliferation of

93   beneficial bacteria (e.g. *Lactobacillus spp.*) and suppress the growth of *Escherichia coli* in the gut [29,30]. Chu

94   et al. [31] found decreased fecal ammonia and amine gas emissions and increased fecal acetate gas emission

95   through supplementation of probiotics (*Aspargillus spp.*, *Saccharomyces spp.* and *Lactobacillus spp.*) compared

96   with the antibiotics fed group. However, some other studies found that supplement of probiotics (*Lactobacillus*

97   *plantarum, Saccharomyces cerevisiae, Bacillus subtilis, Enterococcus Faecium, Lactobacillus acidophilus*)

98   could reduce the ammonia contents in pig manure [32-35]. Wang et al. [35] found decreased fecal ammonia and

99   hydrogen sulfide emissions in 0.1% or 0.2% probiotic supplemented growing pig diet. Kim et al. [25] showed

100 that hydrogen sulfide and ammonia emissions were decreased in *Bacillus licheniformis* and *B. subtilis*

101 supplemented diet in growing pigs. By reducing serum urea nitrogen, ammonia, fecal urease, and ammonium

102 nitrogen content, dietary supplementation with *L. plantarum* led to decreased ammonia emissions in broilers

103 [36]. In a previous experiment, fecal ammonia emission was decreased significantly by probiotics (*B. subtilis*

104 and *E. faecium*) but hydrogen sulfide remained unchanged [37]. Wang and Kim [15] found that probiotic (*L.*

105 *plantarum*) in the weaning pig diet decreased hydrogen sulfide emission without altering ammonia, total

106 mercaptan. On the other hand, Yun et al. [38] found no significant effect on ammonia, hydrogen sulfide,

107 mercaptan, and acetic acid when 0.2% probiotics (*Bacillus, Lactobacillus, Aspergillus*) were given to broiler.

108 The effectiveness of probiotics in reducing noxious gas emissions lies in their complex mechanisms of action

109 within the digestive system. Probiotics function by enhancing the gut's microbial balance, primarily by

110 promoting beneficial bacteria like *Lactobacillus* and suppressing harmful bacteria such as *E. coli* [29,30]. This

111 balanced microbial environment is key to reducing the production of gases like methane, ammonia, and

112 hydrogen sulfide. Previous studies [8,26,28] have shown that probiotics like *B. amyloliquefaciens* and *L. reuteri*

113 improve digestion, leading to a decrease in undigested organic matter in manure. This reduction in undigested

114 material directly correlates with decreased production of methane and other gases during manure

115 decomposition. Additionally, probiotics stimulate the fermentation and digestion of dietary substrates in the gut

116 [4,26]. This process involves the production of enzymes and metabolites that aid in breaking down complex

117 carbohydrates, proteins, and fibers, resulting in increased nutrient availability. Furthermore, the efficient

118 utilization of these nutrients by the gut microbiota means that fewer undigested or unfermented materials are left

119 in the lower digestive tract [4]. This decrease in undigested substrates is a crucial factor in potentially reducing

the production of noxious gases during the fermentation processes within the gut. The action of probiotics in the pig digestive system not only helps restore and maintain a healthy balance of gut bacteria but also optimizes the digestive process. This leads to a reduction in the growth of bacteria responsible for producing noxious gases and a decrease in the amount of undigested substrates available for fermentation, thereby mitigating the production of harmful gases.

Prebiotics

Prebiotics are non-digestible food ingredients that selectively stimulate the growth and activity of beneficial gut microorganisms. They include oligosaccharides, inulin, and other complex carbohydrates that resist digestion in the small intestine and are fermented by beneficial bacteria (e.g. *Lactobacillus*) in the large intestine [9,10]. By promoting the growth of beneficial bacteria that compete with methane-producing microorganisms, prebiotics (lactic acid bacteria) can reduce the production of methane and other gases in the gut [39-41].

Zhao et al. [41] found that feeding fructan to pigs reduced the noxious gas emission by up to 2%. Another study showed that feeding mixture of chicory-inulin, raffinose, cyclodextrin to pigs reduced the production of ammonia and hydrogen sulfide in feces [11]. Supplementation of iso-malto oligosaccharide, partially digested chicory-inulin, raffinose, and cyclodextrin mixture helped to reduce the fecal noxious gas emission [11].

The mechanism by which prebiotics reduce noxious gas emissions in pigs is complex and involves several pathways. First, prebiotics (fructo-oligosaccharides, galacto-oligosaccharides, trans-galactooligosaccharides) can promote the growth of beneficial bacteria in the gut, such as *Lactobacilli* and *Bifidobacteria* [9,40]. Second, prebiotics can improve digestive efficiency by enhancing the absorption of nutrients and reducing the fermentation of undigested food in the large intestine [42,4]. Prebiotics serve as a food source for specific beneficial bacteria in the gut. Prebiotics selectively stimulate the growth and activity of these beneficial bacteria, which have a lower tendency to produce noxious gases compared to other bacteria in the gut [43]. By promoting the growth of these bacteria, prebiotics can shift the microbial balance towards a population that is less likely to produce excessive amounts of gases like hydrogen sulfide and ammonia [9,10,44]. At the same time, prebiotics are not favorable for the growth of certain harmful bacteria. The shift in microbial composition induced by prebiotics can lead to a decrease in the abundance of gas producing bacteria, as they have reduced opportunities for colonization and growth. Once these gas producing bacteria can be controlled, the production of noxious gas also reduced.

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Dietary enzymes

Dietary enzymes, essential naturally occurring proteins, play a pivotal role in pig nutrition by catalyzing critical chemical reactions within the digestive system. These enzymes are widely utilized in the food and feed industry to enhance digestion and nutrient utilization [45,46]. Dietary enzymes are also used in reducing noxious gas emissions in livestock farming, a significant environmental concern highlighted in research by Ravindran [47] and Park et al. [48]. In pigs, the primary cause of noxious gas emissions is the fermentation of undigested feed components in the large intestine, specifically non-starch polysaccharides found in plant-based feeds like soybean meal, corn, and wheat. These complex carbohydrates pose a digestive challenge as pigs inherently lack the enzymes necessary for their breakdown, leading to fermentation and gas production [49,50]. Zhang et al. [51] further explain that microbial fermentation of these undigested proteins and amino acids in the hindgut contributes significantly to ammonia production, a major component of the overall ammonia emission in manure. The beneficial impact on nutrient digestion and gas emission reduction [49,50]. Moreover, the incorporation of these enzymes into pig diets has also been linked to improved pig performance [52-54].

Cho and Kim [52] and Upadhaya et al. [55] observed that the addition of β-mannanase to pig diets did not significantly alter the emission of harmful gases, suggesting that the effectiveness of specific enzymes can vary. Previous studies showed that enzymes like protease and lipase, as well as blends of multiple enzymes (including glucoamylase from *Aspergillus niger*, alpha-amylase from *Bacillus stearothermophilus*, lipase, maltase, and cellulase), can reduce fecal ammonia emissions [12,56,57]. However, these enzymes were less effective in altering emissions of hydrogen sulfide and total mercaptans. McAlpine et al. [58] discovered that pigs fed diets supplemented with protease alone exhibited higher ammonia emissions compared to those on a basal diet. Factors such as enzyme type, dosage, pig age, and diet composition play crucial roles in the efficacy of dietary enzymes in reducing noxious gas emissions.

The mechanisms through which dietary enzymes reduce noxious gas emissions in pig farming are in their ability to improve nutrient utilization and alter fermentation patterns in the gut. Carbohydrases break down complex carbohydrates into simpler sugars, thereby reducing the availability of substrates for fermentation by gut microorganisms that produce gases like methane and hydrogen sulfide. This mechanism is crucial in understanding how dietary enzymes contribute to lower gas emissions [49,50]. Protease enzymes, facilitate the

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hydrolysis of proteins into smaller peptides and amino acids, which are more easily absorbed in the intestine [58,59]. This improved protein digestion reduces the fermentation of undigested proteins in the hindgut, subsequently decreasing ammonia production. The study by McAlpine et al. [58] also suggests that the combination of different enzymes, such as protease and xylanase, can influence fermentation patterns and gas emissions, underscoring the complexity of enzyme interactions in the digestive system. By enhancing the digestion and utilization of nutrients, dietary enzymes not only contribute to better animal health and growth performance [52,53], but also play a significant role in environmental sustainability.

Medicinal Plants

Medicinal plants and herbs have long been used in traditional medicine to treat various diseases. Recently, researchers have been investigating the potential of these plants to reduce gas emissions in pig manure. By reducing the population of microorganisms that produce noxious gases as a byproduct of their metabolism, these emissions can be manipulated [21,60]. Certain compounds in medicinal plant extracts or herb extracts, such as tannins, saponins, and essential oils, have been shown to inhibit the growth and activity of methanogens, thereby reducing methane emissions [61,62]. Bioactive compounds from medicinal plants or herbs can modulate the gut microbiome, improve gut health and function, and increase digestibility, all of which contribute to better nutrient utilization [63,64].

Yan and Kim [64] showed that Eugenol and Cinnamaldehyde extracted from the plants (*Corton zehntneri*, *Occimum gratissimum*, *Cinnamomum verum* and *Cinnamomum cassia*) have the ability to decrease the *E. coli* count in the intestine of finishing pigs, which ultimately helps to reduce the fecal ammonia and hydrogen sulfide emission. Yin et al. [65] indicated the addition of herbal extract, specifically red ginseng, was found to modulate the microflora present in the gastrointestinal tract of pigs. This modulation resulted in a reduction of noxious gas emissions in the pigs. Liu et al. [60] found that *Achyranthes japonica* extracts up to 0.1% reduce the fecal hydrogen sulfide emissions in growing pigs. In contrast, *Salicornia herbacea* supplementation in broiler feed did not show any difference in mercaptan, ammonia, hydrogen sulfide and acetic acid emission [66].

The mechanism of medicinal plant in animal nutrition is a complex process. Plant extracts have some bioactive compound such as Garlic (*Allium sativum*): allicin, alliin, diallyl sulfide, diallyl disulfide [67]; Milk thistle (*Silybum marianum*): silymarin [68]; Turmeric (*Curcuma longa*): curcumin [69]; *A. japonica*: phytoecdysteroid, saponin, polysaccharide, inokosterone and 20-hydroxyecdysone [70]. The bioactive components in plant

206 extracts can improve digestibility in pigs through several mechanisms, including increasing the activity of

207 digestive enzymes [13,41], modulating the gut microbiome [13,21,60], and improving gut health and function

208 [71]. Thus, plant extracts have been shown to improve the digestion and utilization of nutrients by pigs and

209 reduce the amount of undigested material available for fermentation in the manure.

210

211 **Organic Acids**

212 Organic acids are carbon-containing compounds with acidic properties. Organic acids in pig diets lower the pH

213 of the gastrointestinal tract and create an environment less conducive to the growth of *E. coli* bacteria [72].

214 Commonly used organic acids encompass formic acid, propionic acid, butyric acid, acetic acid, and citric acid

215 [73,74]. Organic acids have the potential to improve growth performance, fecal microbial composition, and

216 reduce ammonia, hydrogen sulfide emissions [70,75].

217 In the previous study, pigs were given diets supplemented with protected organic acids (10% malic, 13% citric,

218 and 17% fumaric acids) and there was a considerable decrease in ammonia, hydrogen sulfide emissions

219 [72,76,77]. Moreover, finishing pigs supplemented with a diet containing 0.2% organic acids (10% malic, 13%

220 citric, and 17% fumaric acids) decreased the emission of odorous ammonia and acetic gas [77]. Similarly,

221 Eriksen et al. [78] found that pigs given 2% benzoic acid decreased ammonia emissions by 60-70%.

222 Incorporating organic acids into pig diets caused acidification of the gut. This drop in pH creates conditions that

223 are less favorable for the growth of pathogenic bacteria such as *E. coli*, while promoting lactic acid producing

224 *Lactobacillus spp.* [78,79]. By suppressing the growth of pathogenic bacteria, organic acids indirectly reduce the

225 fermentative reactions that typically generate gases like ammonia and hydrogen sulfide. Upadhaya et al. [77]

226 explained that dietary organic acids can lead to a decrease in the levels of these harmful gases. And then the

227 enhanced gut environment leads to improved nutrient absorption and digestion, further reducing the substrate

228 availability for gas-producing microbial fermentation. Moreover, the inclusion of specific organic acids in pig

229 diets has been shown to directly impact the emissions of odorous gases. Devi et al. [76] and Upadhaya et al. [77]

230 found that diets supplemented with a combination of malic, citric, and fumaric acids led to a significant

231 reduction in ammonia and hydrogen sulfide emissions. Similarly, Eriksen et al. [78] reported a substantial

232 decrease in ammonia emissions with the use of benzoic acid. This approach aligns with the growing need for

233 sustainable agricultural practices that prioritize both animal welfare and environmental conservation.

234

Conclusion

235

236 The production of noxious gas from the pig manure is attributed to the microbial community, mainly sulfate-

237 reducing bacteria responsible for hydrogen sulfide production, methanogenic bacteria for methane production,

238 and finally *E. coli and Salmonella* for carbon dioxide production. Additionally, undigested nutrients in manure,

239 such as organic carbohydrates and organic nitrogen, also contribute to the production of methane, carbon

240 dioxide, ammonia, and hydrogen sulfide. To address this issue, various dietary feed additives are supplied to

241 animals with the aim of enhancing the abundance of beneficial *Lactobacillus* or *Bifidobacterium* microbes in the

242 gastrointestinal tract and improve nutrient digestibility in pigs. This improved microbial community may lead to

243 a reduction in the growth of harmful noxious gas producing bacteria. The introduction of probiotics and

244 prebiotics to the diet can reduce noxious gas-production by improving the gut microbiota. Similarly,

245 incorporating dietary enzymes in pig feeds aids in the digestion of complex carbohydrates and proteins,

246 subsequently decreasing gas production. Medicinal plants, with their unique bioactive components, and organic

247 acids also manipulate the gut microbiota, contributing to the reduction of gas production in pig manure. This

248 study indicated a reduction in harmful gas emissions through feed additives, making pig farming more

249 environmentally friendly and sustainable. The inclusion of dietary probiotics, prebiotics, enzymes, medicinal

250 plants, and organic acids can succeed at farm level as they are easy to implement and involve minimal additional

251 inputs.

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254   **References**

255   1.   US Department of Agriculture, Foreign Agricultural Service (USDA), Livestock and Poultry: World
256   Markets and Trade [Internet]. 2023 [cited 2023 April 13] https://www.fas.usda.gov/data/livestock-and-
257   poultry-world-markets-and-trade

258   2.   Philippe FX, Nicks B. Review on greenhouse gas emissions from pig houses: Production of carbon
259   dioxide, methane and nitrous oxide by animals and manure. Agric Ecosyst Environ. 2015;199:10-25.
260   https://doi.org/10.1016/j.agee.2014.08.015

261   3.   Dennehy C, Lawlor PG, Jiang Y, Gardiner GE, Xie S, Nghiem LD, Zhan X. Greenhouse gas emissions
262   from different pig manure management techniques: a critical analysis. Front Environ Sci Eng.
263   2017;11(3):1-16. https://doi.org/10.1007/s11783-017-0942-6

264   4.   Rowland I, Gibson G, Heinken A, Scott K, Swann J, Thiele I, Tuohy K. Gut microbiota functions:
265   metabolism of nutrients and other food components. Eur J Nutr. 2018;57(1):1-24.
266   https://doi.org/10.1007/s00394-017-1445-8

267   5.   Park JH, Kim IH. Effects of a protease and essential oils on growth performance, blood cell profiles,
268   nutrient retention, ileal microbiota, excreta gas emission, and breast meat quality in broiler chicks. Poult
269   Sci. 2018;97:2854–2860. https://doi.org/10.3382/ps/pey151

270   6.   Jha R, Berrocoso JF. Dietary fiber and protein fermentation in the intestine of swine and their interactive
271   effects on gut health and on the environment: a review. Anim Feed Sci Technol. 2016;212:18–26.
272   https://doi.org/10.1016/j.anifeedsci.2015.12.002

273   7.   Martín R, Langella P. Emerging Health Concepts in the Probiotics Field: Streamlining the Definitions.
274   Front Microbiol. 2019;10:1047. https://doi.org/10.3389/fmicb.2019.01047

275   8.   Yirga H. The use of probiotics in animal nutrition. J Prob Health. 2015;3:132. https://doi.org/10.4172/2329-
276   8901.1000132

277   9.   Davani-Davari D, Negahdaripour M, Karimzadeh I, Seifan M, Mohkam M, Masoumi SJ, Berenjian A,
278   Ghasemi Y. Prebiotics: Definition, Types, Sources, Mechanisms, and Clinical Applications. Foods.
279   2019;8(3):92. https://doi.org/10.3390/foods8030092

280   10.   Slavin J. Fiber and prebiotics: mechanisms and health benefits. Nutrients. 2013;5(4):1417-35.
281   https://doi.org/10.3390/nu5041417

282   11.   Kim DW, Chae SJ, Cho SB, Hwang OH, Lee HJ, Chung WT, Park JC, Kim IC, Kim IH. Effect of
283   prebiotics on intestinal microflora and fermentation products in pig in vitro model. J Anim Sci Technol.
284   2010;52(3):199-204. https://doi.org/10.5187/jast.2010.52.3.199

285   12.   Balasubramanian B, Park JH, Shanmugam S, Kim IH. Influences of enzyme blend supplementation on
286   growth performance, nutrient digestibility, fecal microbiota and meat-quality in grower-finisher pigs.
287   Animals. 2020;10:386. https://doi.org/10.3390/ani10030386

288   13. Long S, Liu S, Wang J, Mahfuz S, Piao X. Natural capsicum extract replacing chlortetracycline enhances
289   performance via improving digestive enzyme activities, antioxidant capacity, anti-inflammatory function,
290   and gut health in weaned pigs. Anim Nutri. 2021;7(2): pp.305-314.
291   https://doi.org/10.1016/j.aninu.2020.12.004

292   14. Yan L, Meng QW, Kim IH. The effect of an herb extract mixture on growth performance, nutrient
293   digestibility, blood characteristics and fecal noxious gas content in growing pigs. Livest Sci. 2011;141:143-
294   147, https://doi.org/10.1016/j.livsci.2011.05.011

295   15. Wang H, Kim IH. Evaluation of dietary probiotic (*Lactobacillus plantarum* BG0001) supplementation on
296   the growth performance, nutrient digestibility, blood profile, fecal gas emission, and fecal microbiota in
297   weaning pigs. Animals (Basel). 2021;11(8):2232. https://doi.org/10.3390/ani11082232

298   16. Osada T, Rom HB, Dahl P. Continuous measurement of nitrous oxide and methane emission in pig units by
299   infrared photoacoustic detection. Trans. ASAE. 1998;41:1109-1114. https://doi.org/10.13031/2013.17256

300   17. Mar KA, Unger C, Walderdorff L, Butler T. Beyond CO_2 equivalence: The impacts of methane on climate,
301   ecosystems, and health. Environ Sci Policy. 2022;134:127-136.
302   https://doi.org/10.1016/j.envsci.2022.03.027

303   18. Qianru C, Xueyuan H, Bing Z, Qing Z, Kaixin Z, Shu L. Regulation of H_2S-induced necroptosis and
304   inflammation in broiler bursa of Fabricius by the miR-15b-5p/TGFBR3 axis and the involvement of
305   oxidative stress in this process. J Hazard Mater. 2021;406:124682.
306   https://doi.org/10.1016/j.jhazmat.2020.124682

307   19. Kim KY, Ko HJ, Lee KJ, Park JB, Kim CN. Temporal and spatial distributions of aerial contaminants in an
308   enclosed pig building in winter. Environ. Res. 2005;99:150-157.
309   https://doi.org/10.1016/j.envres.2004.10.004

310   20. Wang YC, Han MF, Jia TP, Hu XR, Zhu HQ, Tong Z, Lin YT, Wang C, Liu DZ, Peng YZ, Wang G.
311   Emissions, measurement, and control of odor in livestock farms: A review. Sci. Total Environ.
312   2021;776:145735. https://doi.org/10.1016/j.scitotenv.2021.145735

313   21. Sampath V, Shanmugam S, Park JH, Kim IH. The Effect of Black Pepper (Piperine) extract
314   supplementation on growth performance, nutrient digestibility, fecal microbial, fecal gas emission, and
315   meat quality of finishing pigs. Animals. 2020;10:1965. https://doi.org/10.3390/ani10111965

316   22. Fukumoto Y, Suzuki K, Osada T, Kuroda K, Hanajima D, Yasuda T, Haga K. Reduction of nitrous oxide
317   emission from pig manure composting by addition of nitrite-oxidizing bacteria. Environ Sci Technol.
318   2006;40(21):6787-6791. https://doi.org/10.1021/es0611801

319   23. Dang DX, Choi SY, Choi YJ, Lee JH, Castex M, Chevaux E, Saornil D, de Laguna FB, Jimenez G, Kim
320   IH. Probiotic, paraprobiotic, and hydrolyzed yeast mixture supplementation has comparable effects to zinc
321   oxide in improving growth performance and ameliorating post-weaning diarrhea in weaned piglets.
322   Probiotics and Antimicro Prot. 2023. https://doi.org/10.1007/s12602-022-10008-8

323 24. Song D, Lee J, Kim K, Oh H, An J, Chang S, Cho H, Park S, Jeon K, Yoon Y, Yoo Y. Effects of dietary
324 supplementation of *Pediococcus pentosaceus* strains from kimchi in weaned piglet challenged with
325 *Escherichia coli* and *Salmonella enterica*. J Anim Sci Technol. 2023;65(3):611.

326 25. Kim YJ, Cho SB, Song MH, Lee SI, Hong SM, Yun W, Lee JH, Oh HJ, Chang SY, An JW, Go YB, Song
327 DC, Cho HA, Kim HB, Cho JH. Effects of different *Bacillus licheniformis* and *Bacillus subtilis* ratios on
328 nutrient digestibility, fecal microflora, and gas emissions of growing pigs. J Anim Sci Technol.
329 2022;64(2):291-301. https://doi.org/10.5187/jast.2022.e12

330 26. Kenny M, Smidt H, Mengheri E, Miller B. Probiotics - do they have a role in the pig industry? Animal.
331 2011;5:462-470. https://doi.org/10.1017/S175173111000193X

332 27. Liu Y, Wang J, Wu C. Modulation of gut microbiota and immune system by probiotics, pre-biotics, and
333 post-biotics. Frontiers in Nutri. 2022;8:634897. https://doi.org/10.3389/fnut.2021.634897

334 28. Oh JK, Vasquez R, Kim SH, Hwang IC, Song JH, Park JH, Kim IH, Kang DK. Multispecies probiotics
335 alter fecal short-chain fatty acids and lactate levels in weaned pigs by modulating gut microbiota. J Anim
336 Sci Technol. 2021;63(5):1142-1158. https://doi.org/10.5187/jast.2021.e94

337 29. Loyon L, Burton CH, Misselbrook T, Webb J, Philippe FX, Aguilar M, Doreau M, Hassouna M, Veldkamp
338 T, Dourmad JY, Bonmati A. Best available technology for European livestock farms: Availability,
339 effectiveness and uptake. J Environ Manage. 2016;166:1-11.
340 https://doi.org/10.1016/j.jenvman.2015.09.046

341 30. Sureshkumar S, Park JH, Kim IH. A preliminary evaluation on mixed probiotics as an antimicrobial
342 spraying agent in growing pig barn. J Anim Sci Technol. 2022;64(6):1035-1045.
343 https://doi.org/10.5187/jast.2022.e69

344 31. Chu GM, Lee SJ, Jeong HS, Lee SS. Efficacy of probiotics from anaerobic microflora with prebiotics on
345 growth performance and noxious gas emission in growing pigs. Anim Sci J. 2011;82(2):282-290.
346 https://doi.org/10.1111/j.1740-0929.2010.00828.x

347 32. Hassan MR, Ryu KS. Naturally derived probiotic supplementation effects on physiological properties and
348 manure gas emission of broiler chickens. J Agri Life Sci. 2012;46:119-127.

349 33. Upadhaya SD, Kim SC, Valientes RA, Kim IH. The Effect of *Bacillus*-based feed additive on growth
350 performance, nutrient digestibility, fecal gas emission, and pen cleanup characteristics of growing-finishing
351 pigs. Asian-Australas J Anim Sci. 2015;28(7):999-1005. https://doi.org/10.5713/ajas.15.0066

352 34. Zhang ZF, Lee JM, Kim IH. Effects of *Enterococcus faecium* DSM 7134 on weanling pigs were influenced
353 by dietary energy and crude protein density. Livestock science. 2014;169:106-111.
354 https://doi.org/10.1016/j.livsci.2014.09.022

355 35. Wang J, Li S, Tang W, Diao H, Zhang H, Yan H, Liu J. Dietary Complex Probiotic Supplementation
356 Changed the Composition of Intestinal Short-Chain Fatty Acids and Improved the Average Daily Gain of
357 Growing Pigs. Vet Sci. 2023;10(2):79. https://doi.org/10.3390/vetsci10020079

358 36. Liu X, Cao G, Qiu K, Dong Y, Hu C. *Lactobacillus plantarum* Decreased Ammonia Emissions through
359   Modulating Cecal Microbiotain Broilers Challenged with Ammonia. Animals. 2023;13(17):2739.
360   https://doi.org/10.3390/ani13172739

361 37. Liu J, Cao S, Liu J, Xie Y, Zhang H. Effect of probiotics and xylo-oligosaccharide supplementation on
362   nutrient digestibility, intestinal health and noxious gas emission in weanling pigs Anim Biosci.
363   2018;31(10):1660-1669. https://doi.org/10.5713/ajas.17.0908

364 38. Yun W, Lee DH, Choi YI, Kim IH, Cho JH. Effects of supplementation of probiotics and prebiotics on
365   growth performance, nutrient digestibility, organ weight, fecal microbiota, blood profile, and excreta
366   noxious   gas   emissions   in   broilers.   J   Appl   Poult   Res.   2017;26(4):584-592.
367   https://doi.org/10.3382/japr/pfx033

368 39. Doyle N, Mbandlwa P, Kelly WJ, Attwood G, Li Y, Ross RP, Stanton C, Leahy S. Use of lactic acid
369   bacteria to reduce methane production in ruminants, a critical review. Front Microbiol. 2019;10:2207.
370   https://doi.org/10.3389/fmicb.2019.02207

371 40. Li J, Kim IH. Yeast Cell Wall and Propolis in Growing Pigs. Anim Sci J. 2014;85:698-705.
372   https://doi.org/10.1111/asj.12195

373 41. Zhao PY, Wang JP, Kim IH. Evaluation of dietary fructan supplementation on growth performance, nutrient
374   digestibility, meat quality, fecal microbial flora, and fecal noxious gas emission in finishing pigs. J Anim
375   Sci. 2013;91:5280-5286.

376 42. Gibson GR, Hutkins R, Sanders ME, Prescott SL, Reimer RA, Salminen SJ, Scott K, Stanton C, Swanson
377   KS, Cani PD, Verbeke K. Expert consensus document: The International Scientific Association for
378   Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. Nat Rev
379   Gastroenterol Hepatol. 2017;14(8):491-502. https://doi.org/10.1038/nrgastro.2017.75

380 43. Wang X, Gibson GR, Sailer M, Theis S, Rastall RA. Prebiotics Inhibit Proteolysis by Gut Bacteria in a
381   Host Diet-Dependent Manner: a Three-Stage Continuous In Vitro Gut Model Experiment. Appl Environ
382   Microbiol. 2020; 86(10):e02730-19. https://doi.org/10.1128/AEM.02730-19

383 44. Holscher   HD.   Dietary   fiber   and   prebiotics   and   the   gastrointestinal   microbiota.   Gut
384   Microbes. 2017;8(2):172-184. https://doi.org/10.1080/19490976.2017.1290756

385 45. Munezero O, Kim IH. Effects of protease enzyme supplementation in weanling pigs' diet with different
386   crude protein levels on growth performance and nutrient digestibility. J Anim Sci Technol. 2022;64(5):854-
387   862. https://doi.org/10.5187/jast.2022.e51

388 46. Song M, Kim B, Cho JH, Kyoung H, Park S, Cho JY, Park K II, Kim HB, Lee JJ. Effects of dietary
389   protease supplementation on growth rate, nutrient digestibility, and intestinal morphology of weaned pigs. J
390   Anim Sci Technol. 2022;64(3):462-470. https://doi.org/10.5187/jast.2022.e28

391 47. Ravindran V. Feed enzymes: The science, practice, and metabolic realities. J Appl Poult Res.
392   2013;22(3):628-636. https://doi.org/10.3382/japr.2013-00739

48. Park S, Lee J, Hong S, Yun W, Oh H, Song D, Chang S, An J, Cho H, Jeon K, Cho J. Supplementation of protease and different nutrient density diets in growing-finishing pigs. J Anim Sci Technol. 2023 https://doi.org/10.5187/jast.2023.e55

49. Trabue S, Kerr B, Bearson B, Hur M, Parkin T, Wurtle E, Ziemer C. Microbial community and chemical characteristics of swine manure during maturation. J Environ Qual. 2016;45:1144-1152. https://doi.org/10.2134/jeq2015.09.0446

50. Adeola O, Cowieson A. Board-invited review: opportunities and challenges in using exogenous enzymes to improve nonruminant animal production. J Anim Sci. 2011;89:3189-3218. https://doi.org/10.2527/jas.2010-3715

51. Zhang S, Zhong R, Gao L, Liu Z, Chen L, Zhang H. Effects of Optimal Carbohydrase Mixtures on Nutrient Digestibility and Digestible Energy of Corn- and Wheat-Based Diets in Growing Pigs. Animals (Basel). 2020;10(10):1846. https://doi.org/10.3390/ani10101846

52. Cho JH, Kim IH. Effects of beta mannanase and xylanase supplementation in low energy density diets on performances, nutrient digestibility, blood profiles and meat quality in finishing pigs. Asian J Anim Vet Adv. 2013;8(4):622-630. https://doi.org/10.3923/ajava.2013.622.630

53. Kim JS, Ingale SL, Lee SH, Kim KH, Lee JH, Chae BJ. Effects of energy levels of diet and β-mannanase supplementation on growth performance, apparent total tract digestibility and blood metabolites in growing pigs. Anim Feed Sci Technol. 2013;186(1-2):64–70. https://doi.org/10.1016/j.anifeedsci.2013.08.008

54. Mok CH, Lee JH, Kim BG. Effects of exogenous phytase and β-mannanase on ileal and total tract digestibility of energy and nutrient in palm kernel expeller-containing diets fed to growing pigs. Anim Feed Sci Technol. 2013;186(3-4):209–213. https://doi.org/10.1016/j.anifeedsci.2013.10.008

55. Upadhaya SD, Park JW, Lee JH, Kim IH. Efficacy of β-mannanase supplementation to corn–soya bean meal-based diets on growth performance, nutrient digestibility, blood urea nitrogen, faecal coliform and lactic acid bacteria and faecal noxious gas emission in growing pigs. Archiv Anim Nutri. 2016;70(1):33-43. https://doi.org/10.1080/1745039X.2015.1117697

56. Tactacan G, Cho S, Cho J, Kim I. Performance responses, nutrient digestibility, blood characteristics, and measures of gastrointestinal health in weanling pigs fed protease enzyme. Anim Biosci. 2016;29(7):998-1003. https://doi.org/10.5713/ajas.15.0886

57. Liu J, Cao S, Liu J, Pu J, Chen L, Zhang H. Effects of dietary energy and lipase levels on nutrient digestibility, digestive physiology and noxious gas emission in weaning pigs Anim Biosci. 2018;31(12):1963-1973. https://doi.org/10.5713/ajas.18.0087

58. Mc Alpine PO, O'shea CJ, Varley PF, Solan P, Curran T, O'doherty JV. The effect of protease and nonstarch polysaccharide enzymes on manure odor and ammonia emissions from finisher pigs. J Anim Sci. 2012;90: 369-371. https://doi.org/10.2527/jas.53948

59. Lei XJ, Cheong JY, Park JH, Kim IH. Supplementation of protease, alone and in combination with fructooligosaccharide to low protein diet for finishing pigs. Anim Sci J. 2017;88(12):1987-1993. https://doi.org/10.1111/asj.12849

430 60. Liu X, Lee S, Kim IH. *Achyranthes japonica* extracts supplementation to growing pigs positively
431   influences growth performance, nutrient digestibility, fecal microbial shedding, and fecal gas emission.
432   Anim Biosci. 2021;34(3):427-433. https://doi.org/10.5713/ajas.20.0012

433 61. Ramdani D, Yuniarti E, Jayanegara A, Chaudhry AS. Roles of Essential Oils, Polyphenols, and saponins of
434   medicinal plants as natural additives and anthelmintics in ruminant diets: A Systematic Review. Animals.
435   2023;13:767. https://doi.org/10.3390/ani13040767

436 62. Mueller-Harvey I. Review unravelling the conundrum of tannins in animal nutrition and health. J Sci Food
437   Agric. 2006;86:2010-2037. https://doi.org/10.1002/jsfa.2577

438 63. Shehata AA, Yalçın S, Latorre JD, Basiouni S, Attia YA, Abd El-Wahab A, Visscher C, El-Seedi HR, Huber
439   C, Hafez HM, Eisenreich W. Probiotics, prebiotics, and phytogenic substances for optimizing gut health in
440   poultry. Microorganisms. 2022;10(2):395. https://doi.org/10.3390/microorganisms10020395

441 64. Yan L, Kim IH. Effect of eugenol and cinnamaldehyde on the growth performance, nutrient digestibility,
442   blood characteristics, fecal microbial shedding and fecal noxious gas content in growing pigs. Asian-
443   Australas J Anim Sci. 2012;25(8):1178. https://doi.org/10.5713/ajas.2012.12111

444 65. Yin J, Kim HS, Kim YM, Kim IH. Effects of dietary fermented red ginseng marc and red ginseng extract
445   on growth performance, nutrient digestibility, blood profile, fecal microbial, and noxious gas emission in
446   weanling pigs. J Appl Anim Res. 2018;46:1084-9. https://doi.org/10.1080/09712119.2018.146 6708

447 66. Jiao Y, Hosseindoust A, Zhang WL, Kim IH. Effects of *Salicornia herbacea* on growth performance, meat
448   quality, excreta microbial populations, and noxious gas emissions in broiler chicks. J Poult Sci.
449   2019;56(1):44-51., https://doi.org/10.2141/jpsa.0170210

450 67. Shang A, Cao SY, Xu XY, Gan RY, Tang GY, Corke H, Mavumengwana V, Li HB. Bioactive Compounds
451   and Biological Functions of Garlic (*Allium sativum* L.). Foods. 2019;8(7):246.
452   https://doi.org/10.3390/foods8070246

453 68. Aziz M, Saeed F, Ahmad N, Ahmad A, Afzaal M, Hussain S, Mohamed AA., Alamri, MS, Anjum FM.
454   Biochemical profile of milk thistle (*Silybum Marianum* L.) with special reference to silymarin content.
455   Food Sci Nutr. 2021;9(1):244-250. https://doi.org/10.1002/fsn3.1990

456 69. Zhang HA, Kitts DD. Turmeric and its bioactive constituents trigger cell signaling mechanisms that protect
457   against diabetes and cardiovascular diseases. Mol Cell Biochem. 2021;476(10):3785-3814.
458   https://doi.org/10.1007/s11010-021-04201-6

459 70. Hossain MM, Hwang HS, Pang M, Choi MK, Kim IH. Effect of dietary *Achyranthes japonica* extract on
460   growth performance of growing pigs and absorption rate of quercetin in blood. J Anim Sci Technol. 2023
461   https://doi.org/10.5187/jast.2023.e23

462 71. Szabó C, Kachungwa Lugata J, Ortega ADSV. Gut Health and Influencing Factors in Pigs. Animals.
463   2023;13:1350. https://doi.org/10.3390/ani13081350

464 72. Stratford M, Eklund T. Organic acids and esters. In Food Preservatives; Springer: Boston, MA, USA, 2003;
465   pp. 48–84. https://doi.org/10.1007/978-0-387-30042-9_4

466 73. Suiryanrayna MV, Ramana JV. A review of the effects of dietary organic acids fed to swine. J Anim Sci
467   Biotechnol. 2015 21;6:45 https://doi.org/10.1186/s40104-015-0042-z

468 74. Nguyen DH, Seok WJ, Kim IH. Organic Acids Mixture as a Dietary Additive for Pigs-A Review. Animals.
469   2020;10:952. https://doi.org/10.3390/ani10060952

470 75. Upadhaya SD, Lee KY, Kim IH. Influence of protected organic acid blends and diets with different nutrient
471   densities on growth performance, nutrient digestibility and faecal noxious gas emission in growing pigs.
472   Vet Med. 2014;59:491–497. https://doi.org/10.17221/7779-vetmed

473 76. Devi SM, Lee KY, Kim IH. Analysis of the effect of dietary protected organic acid blend on lactating sows
474   and their piglets. Rev Bras Zootec. 2016;45:39–47. https://doi.org/10.1590/S1806-92902016000200001

475 77. Upadhaya SD, Lee KY, Kim IH. Protected organic acid blends as an alternative to antibiotics in finishing
476   pigs. Asian Australas J Anim Sci. 2014;27:1600–1607. https://doi.org/10.5713/ajas.2014.14356

477 78. Eriksen J, Adamsen APS, Nørgaard JV, Poulsen HD, Jensen BB, Petersen SO. Emissions of sulfur-
478   containing odorants, ammonia, and methane from pig slurry: Effects of dietary methionine and benzoic
479   acid. J Environ Qual. 2010;39:1097–1107. https://doi.org/10.2134/jeq2009.0400

480 79. Hernández F, García V, Madrid J, Orengo J, Catalá P, Megías MD. Effect of formic acid on performance,
481   digestibility, intestinal histomorphology and plasma metabolite levels of broiler chickens. Br Poult Sci.
482   2006;47:50–56. https://doi.org/10.1080/00071660500475574

483 80. Chen YJ, Son KS, Min BJ, Cho JH, Kwon OS, Kim IH. Effects of dietary probiotic on growth
484   performance, nutrients digestibility, blood characteristics and fecal noxious gas content in growing pigs.
485   Asian-Austral J Anim Sci. 2005;18:1464–1468. https://doi.org/10.5713/ajas.2005.1464

486 81. Wang Y, Cho JH, Chen YJ, Yoo JS, Huang Y, Kim HJ, Kim IH. The effect of probiotic BioPlus 2B® on
487   growth performance, dry matter and nitrogen digestibility and slurry noxious gas emission in growing pigs.
488   Livest Sci. 2009;120(1-2):35-42. https://doi.org/10.1016/j.livsci.2008.04.018

489 82. Prenafeta-Boldú FX, Fernández B, Viñas M, Lizardo R, Brufau J, Owusu-Asiedu A, Walsh MC, Awati A.
490   Effect of Bacillus spp. direct-fed microbial on slurry characteristics and gaseous emissions in growing pigs
491   fed with high fibre-based diets. Animal. 2017;11(2): 209-218. https://doi.org/10.1017/S1751731116001415

492 83. Lee SJ, Shin NH, Ok JU, Jung HS, Chu GM, Kim JD, Kim IH, Lee SS. Effects of dietary synbiotics from
493   anaerobic microflora on growth performance, noxious gas emission and fecal pathogenic bacteria
494   population in weaning pigs. Asian-australas J Anim Sci. 2009;22(8):1202-1208.
495   https://doi.org/10.5713/ajas.2009.90045

496 84. Lan R, Li T, Kim IH. Effects of xylanase supplementation on growth performance, nutrient digestibility,
497   blood parameters, fecal microbiota, fecal score and fecal noxious gas emission of weaning pigs fed corn-
498   soybean meal-based diet. Anim Sci J. 2017;88(9):1398-1405. https://doi.org/10.1111/asj.12771

17

499 85. Zhao P, Li H, Lei Y, Li T, Kim S, Kim IH. Effect of fermented medicinal plants on growth performance,
500   nutrient digestibility, fecal noxious gas emissions, and diarrhea score in weanling pigs. J Sci Food Agric.
501   2016;96:1269-1274. https://doi.org/10.1002/jsfa.7217

502 86. Dang DX, Kim YM, Kim IH. Effects of a root extract from *Achyranthes Japonica* Nakai on the growth
503   performance, blood profile, fecal microbial community, fecal gas emission, and meat quality of finishing
504   pigs. Livest Sci. 2020;239:104160. https://doi.org/10.1016/j.livsci.2020.104160

505 87. Hossain MM, Jayaraman B, Kim SC, Lee KY, Kim IH, Nyachoti CM. Effects of a matrix-coated organic
506   acids and medium-chain fatty acids blend on performance, and in vitro fecal noxious gas emissions in
507   growing   pigs   fed   in-feed   antibiotic-free   diets.   Can   J   Anim   Sci.   2018;98:433–442.
508   https://doi.org/10.1139/cjas-2017-0053

509 88. Upadhaya SD, Lee KY, Serpunja S, Song TH, Kim IH. Growth performance, nutrient digestibility, fecal
510   microbiota and fecal noxious gas emission in weaning pigs fed high- and low-density diet with and without
511   protected   organic   acid   blends.   Anim   Feed   Sci   Technol.   2018;239:1–8.
512   https://doi.org/10.1016/j.anifeedsci.2017.12.013

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520 **Table 1:** Different feed additives for reducing noxious gas emission in pig

Type of additive	Additive	Dose	Animal	Result	References
Probiotics	*Bacillus organisms*	0.00625% (1.47×10^8 CFU of *Bacillus spp.*/g)	Growing-finishing pigs	Reduced fecal NH_3 emission was found while fecal total mercaptans, H_2S and volatile fatty acid was not altered.	[33]
	L. plantarum	0.20% (1.30×10^7 CFU/g of *L. plantarum* /g)	Weaning pigs	Fecal NH_3, H_2S, total mercaptan, and acetic acid was not changed	[15]
	Probiotics mixture (*B. licheniformis*, *B. subtilis*, *L. acidophilus* and *S. cerevisiae*)	0.20% (5.1×107 CFU/g *B. licheniformis*, 6.3×107 CFU/g *B. subtilis*, 4.3×107 CFU/g *L. acidophilus* and 2.5×107 CFU/g *S. cerevisiae*)	Growing pigs	Fecal NH_3, H_2S decreased while methyl mercaptans, acetic acid, CO_2 was not changed	[35]
	Probiotic complex (*L. acidophilus*, *Saccharomyces cerevisae*, and *B. subtilis*)	0.20% (1.0×10^7 CFU/g *L. acidophilus*, 4.3×10^6 CFU/g *Saccharomyces cerevisae* and 2.0×10^6 CFU/g *B. subtilis*)	Growing pigs	Fecal NH_3-N emission decreased while acetic acid, propionic acid and butyric acid was not affected	[80]
	E. faecium DSM 7134	1.0×10^{10} CFU/g *E. faecium*	Weanling pigs	Fecal NH_3 emission was reduced but H_2S was remained unaffected	[34]
	Probiotics complex (*B. licheniformis* and *B. subtilis*)	0.2% (3×10^7 CFU/g of *B. licheniformis* and 3×10^7 CFU/g of *B. subtilis*)	Growing pigs	Fecal NH_3 and H_2S emission decreased after day 4 of fermentation.	[25]
	B. subtilis and *B. licheniformis*	0.2% (3.2×109 CFU/g of *B. subtilis* and *B. licheniformis*)	Growing pigs	Fecal NH_3 emission was lowered but while H_2S and mercaptan emission was not affected	[81]
	Aspargillus spp., *Saccharomyces spp.* and *Lactobacillus spp*	0.2% (*Aspargillus spp.*, *Saccharomyces spp.* and *Lactobacillus spp.*)	Growing pigs	Decreased fecal propionate, ammonia and amine gas emissions, and increased fecal acetate gas emission	[31]
	Bacillus spp.	0.05% (3×108 CFU/g *Bacillus spp.*)	Growing pigs	Methane and ammonia volatilization decreased	[82]
Prebiotics	Fructan	2.0%	Finishing pigs	Fecal ammonia, hydrogen sulfide, total mercaptans decreased	[41]
	S. cerevisiae cell wall extract and poplar propolis ethanol extract	0.10%	Growing pigs	Fecal NH_3 and H_2S was decreased linearly	[40]

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Synbiotics	Probiotics from bacteria or yeast or mold or compounds of bacteria, yeast and mold.	0.2%	Weaning pigs	Ammonia and amine gas emission decreased in bacteria synbiotics, H_2S was decreased in bacteria synbiotics, yeast synbiotics, or mold synbiotics	[83]
Enzyme	Enzyme blend (glucoamylase from *A. niger*, alpha-amylase from *B. stearothermophilos*, lipase, maltase, cellulose, protease)	1.0%	Grower-finisher Pigs	Fecal NH_3 decreased while H_2S and total mercaptans remained unchanged	[12]
	Protease and fructo-oligosaccharide	0.05% protease and/ or 0.1% fructo-oligosaccharide	finishing pigs	Total mercaptan and H_2S was not changed but fecal ammonia emission decreased in both protease or fructo-oligosaccharide	[59]
	Xylanase	0.01%	Weaning pigs	NH_3 and H_2S decreased while total mercaptans emission was not altered.	[84]
Medicinal plant	Black pepper (piperine) extract	0.4%	Finishing pigs	Fecal NH_3 and methyl mercaptans, and acetic acid decreased linearly. fecal H_2S and CO_2 was not altered.	[21]
	A. japonica extracts	0.10%	Growing pigs	Fecal H_2S emission decreased linearly while fecal NH_3 and total mercaptans emission was unaffected	[60]
	Fermented *Gynura procumbens*, *Rehmannia glutinosa* and *Scutellaria baicalensis*	0.2%	Weaning pigs	Fecal NH_3 and, total mercaptans and H_2S decreased linearly	[85]
	Herb extracts mixture (buckwheat, thyme, curcuma, black pepper and ginger)	0.025%	Growing pigs	Fecal NH_3 and H_2S emission decreased in the day 2 and day 1 of fermentation respectively	[14]
	Achyranthes japonica Nakai root extract	0.02%	Finishing pigs	Fecal NH_3 decreased but fecal H_2S and R-SH emissions was not altered	[86]
Organic acid	Mixture of fumaric acid, citric acid, malic acid, and medium chain fatty acid	1.0%	Growing pigs	Fecal H_2S emission reduced but ammonia and total mercaptans was unaffected.	[75]
	Fumaric acid, citric acid, malic acid, capric	0.2%	Growing pigs	NH_3 and acetic acid decreased but H_2S was not affected	[87]

acid, and caprylic acid				
Fumaric acid, citric acid, malic acid, capric acid, and caprylic acid	0.2%	Sow	NH_3 and H_2S decreased but acetic acid was not altered	[76]
Fumaric acid, citric acid, malic acid, capric acid, and caprylic acid	0.2%	Weaning pigs	NH_3 and H_2S was not altered	[88]

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Figure 1. The role of probiotics, prebiotics, dietary enzymes, plant additives, and organic acid to reduce the gas emission
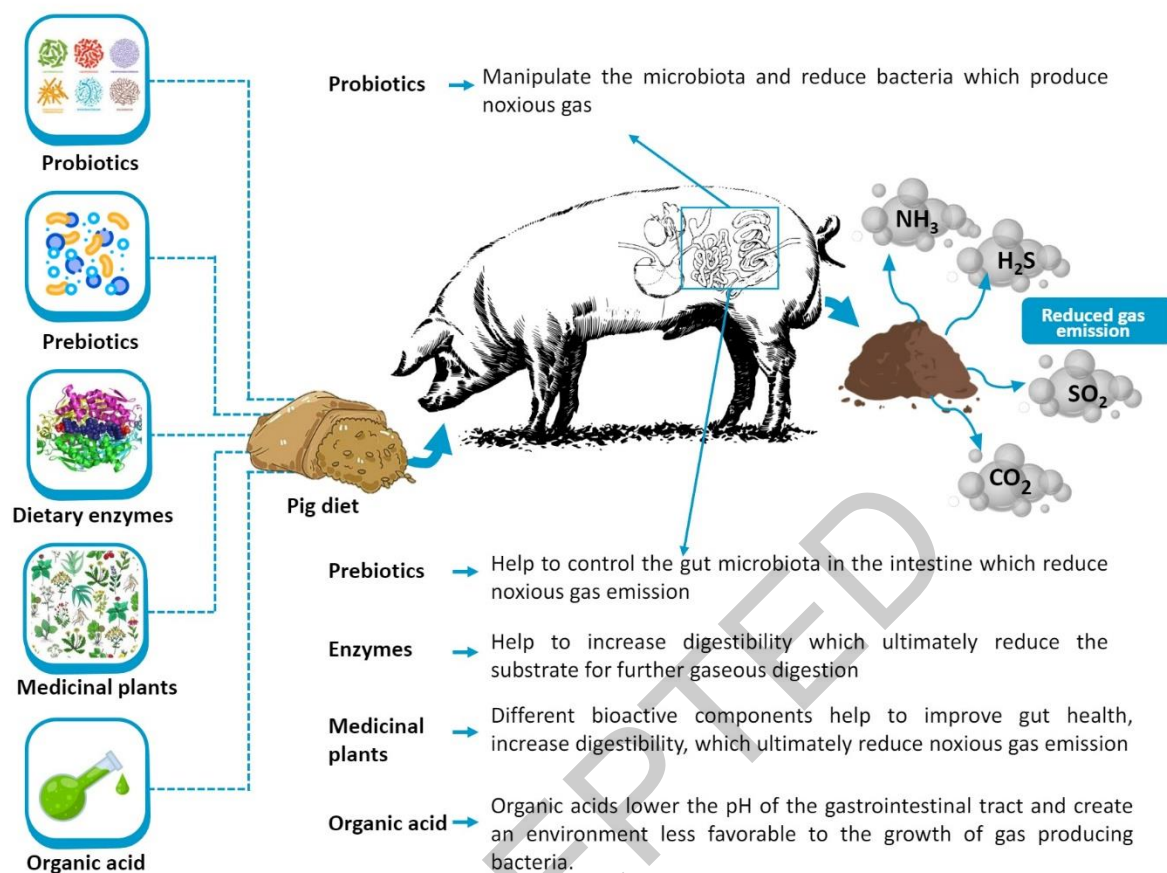
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526 **Figure 1. The role of probiotics, prebiotics, dietary enzymes, plant additives, and organic acid to reduce**

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