



Effects of dietary fresh fermented soybean meal on growth performance, ammonia and particulate matter emissions, and nitrogen excretion in nursery piglets*

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Abstract: This study was conducted to investigate the effects of fresh fermented soybean meal (FSM) on the growth performance of nursery piglets, nitrogen excretion in feces, and the concentrations of ammonia (NH₃) and particulate matter (PM) in the piggery. A total of 472 nursery piglets (Landrace×Yorkshire, (16.3±0.36) kg body weight) were randomly allocated into two treatments with 236 pigs in each treatment. The pigs were fed the basal diet without fresh FSM (control) or diet containing 10% (100 g/kg) fresh FSM (FSM group), and the crude protein content of the two groups was consistent. The feeding trial lasted for 28 d. The results showed that the pigs fed fresh FSM had increased ($P<0.05$) average daily gain (ADG) compared with the control. There was no significant difference ($P>0.05$) in feed to gain ratio (F:G) between the two groups. During the whole experiment, the concentration of NH₃ in the piggery decreased ($P<0.05$) by 19.0%, and the concentrations of PM (PM₁₀ and PM_{2.5}) in the piggery decreased ($P<0.05$) by 19.9% and 11.6%, respectively, in the FSM group, compared with the control. The ammonia nitrogen and nitrite content in feces increased ($P<0.05$) by 32.9% and 28.4%, respectively, in the FSM group. The fecal pH declined ($P<0.05$) significantly in the FSM group compared with the control. At the end of experiment, total protein (TP) concentration was increased ($P<0.05$) significantly and blood urea nitrogen (BUN) concentration was decreased ($P<0.05$) for pigs fed the diet with fresh FSM. The results indicated that dietary fresh FSM not only improved the growth performance of nursery piglets, but also reduced the NH₃ concentration in the piggery due to nitrogen conversion, and decreased the concentrations of PM₁₀ and PM_{2.5} in the piggery.

Key words: Fresh fermented soybean meal; Ammonia; Particulate matter; Nitrogen conversion; Nursery piglet
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1 Introduction

Livestock production is now one of the major contributors to environmental problems. Among these, greenhouse gas emission is one of the most serious problems (Ilea, 2009). Lots of poisonous and

harmful gases are generated from the barn and in the process of animal fecal sewage treatment (Webb *et al.*, 2014), endangering animals and human health. This also captures the attention of the pig-breeding industry. Among these gases, ammonia (NH₃) is the foremost pollutant gas contributing to nitrogen eutrophication of ecosystems, acid rain, and soil acidification (Krupa, 2003). Ammonia also has a direct effect on animal health, inducing infectious disease (Banhazi *et al.*, 2008). Reducing NH₃ emissions of the pig-breeding industry contributes to promoting animal growth, improving economic benefits of farms, and

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lessening environmental pollution. Particulate matter (PM) is also an important environmental pollutant produced in animal husbandry, causing haze problems of concern to the world and endangering the health of animals and humans (Vogelzang *et al.*, 2000). Factors that influence NH₃ emissions and PM formation include the fecal sewage treatment system (Hoff *et al.*, 2006), feeding technology, and the housing system (Zhou *et al.*, 2015). The dietary composition is also one of the factors (Chiavegato *et al.*, 2015).

Techniques such as treatment of sewage, biofiltration of ventilation air, and floor design for separating feces and urine have been developed to reduce emissions of NH₃ and PM (Portejoie *et al.*, 2003; Ye *et al.*, 2007; Dumont *et al.*, 2014), but these measures are often impractical or uneconomical for application in livestock production (Rigolot *et al.*, 2010). Reducing NH₃ emissions by regulating dietary composition is considered economical and feasible. Optimization of feed ingredients and formula could improve the utilization of nitrogen, and then reduce NH₃ emissions. Fermented soybean meal (FSM) is one of the most concerned ingredients. The fermentation process increases the number of small-size peptides and the activity of the digestive enzymes compared with soybean meal (Mukherjee *et al.*, 2016).

Fresh FSM was obtained from the fermentation production of soybean meal using a compound bacterium. Without drying, it had high humidity and rich probiotics, which may contribute to the nutrient to be digested and be easily absorbed by animals. We hypothesized that the fresh FSM could improve air quality in the piggery because of its special properties. Therefore, the objective of this study was to investigate the effects of fresh FSM on growth performance of nursery piglets, on nitrogen excretion in feces, and on the concentrations of NH₃ and PM in the piggery.

2 Materials and methods

2.1 Fresh fermented soybean meal

The fresh FSM was provided by a commercial company (Zhejiang Chengyuan Biotechnology Co., Ltd., China). Dried soybean meals were soaked in distilled water at 4 °C overnight. Hydrated soybean meals were cooked in a steam tank at 60–70 °C for 1 h.

The cooked soybean meals were then allowed to cool to room temperature. *Lactobacillus plantarum* (CGMCC No. 1.1209), *Bacillus subtilis* MA 139 and *Saccharomyces cerevisiae* (CGMCC No. 2.0707) were stirred evenly at a ratio of 1:2:2 (volume ratio). Then soybean meals were incubated with *L. plantarum*, *B. subtilis*, and *S. cerevisiae* at 37 °C for 72 h. Sterile distilled water was added to achieve a certain initial moisture content. The total inoculum was 0.4% of the weight of the soybean meals. The initial temperature was controlled at 30 °C and the fermentation process lasted for 72 h. After fermentation, no drying process was required.

2.2 Experimental design, animals, and diets

A total of 472 nursery piglets (Landrace×Yorkshire, 50% male and 50% female) with an average body weight of (16.3±0.36) kg were randomly allocated to two treatments with 236 piglets in each treatment group. Each treatment group in one piggery consisted of 12 pens, and 19 to 20 piglets per pen. A pen served as the experimental unit. Each pen was equipped with a nipple bowl drinker and a long cement trough. The pigs had free access to feed and water during the experiment. The pig room temperature was maintained at 20 to 22 °C and the relative humidity was 50% to 70%. This feeding trial lasted for 28 d. The present study followed the laws and regulations that control experiments and procedures in live animals in China, under the supervision of the Chinese Animal Research Authority.

The pigs in the control group were fed diet without fresh FSM as the basal diet. The pigs in the FSM group were fed the basal diet with 10% (100 g/kg) fresh FSM. The composition and nutrient contents of the experimental diets are shown in Table 1. Experimental diets were formulated to have similar nutrient contents to meet nutritional requirements for nursery pigs recommended by the National Research Council (NRC, 2012).

2.3 Measurements and sample collection

The diets were analyzed for crude protein (N×6.25; method 988.03), crude fat (method 920.39A), ash (method 942.05), calcium (method 968.08), and total phosphorus (method 946.06) according to Association of Official Analytical Chemists (AOAC, 2006) Official Methods. Individual amino acid was

Table 1 Ingredients and nutrient composition of the experimental diets¹

Item	Control	FSM
Ingredient		
Corn (%)	58.5	56.5
Soybean meal (%)	21.0	13.0
Puffed soybean (%)	6.0	6.0
Fresh FSM (%)		10.0
Fish meal (%)	4.0	4.0
Whey powder (%)	5.0	5.0
Soybean oil (%)	2.0	2.0
Salt (%)	0.3	0.3
Stone powder (%)	1.2	1.2
Calcium hydrogen phosphate (%)	1.0	1.0
Vitamin premix ² (%)	0.2	0.2
Trace mineral premix ³ (%)	0.5	0.5
L-Lysine (%)	0.20	0.18
DL-Methionine (%)	0.05	0.07
L-Threonine (%)	0.05	0.05
Analyzed nutrient level⁴		
Metabolizable energy (MJ/kg) ⁵	13.85	13.83
Crude protein (%)	17.50±0.85	17.47±0.70
Crude fat (%)	4.22±0.32	4.16±0.24
Ash (%)	6.47±0.40	6.59±0.42
Calcium (%)	0.77±0.06	0.76±0.03
Phosphorus, total (%)	0.69±0.05	0.69±0.04
Lysine (%)	1.24±0.06	1.23±0.05
Methionine (%)	0.35±0.02	0.35±0.03
Threonine (%)	0.68±0.02	0.71±0.02

¹ Experimental diets were: dietary inclusion of 100 g/kg fresh fermented soybean meal (FSM) in the FSM group, and no fresh FSM in diet as the control. ² Provided per kilogram of diet: vitamin A, 10000 IU; vitamin D₃, 1500 IU; vitamin E, 60 mg; vitamin K₃, 0.5 mg; vitamin B₁, 5 mg; vitamin B₂, 20 mg; pantothenate acid, 12 mg; niacin, 20 mg; folic acid, 1.25 mg. ³ Provided per kilogram of diet: Fe, 150 mg as iron sulfate; Cu, 100 mg as copper sulfate; Zn, 140 mg as zinc oxide; Mn, 35 mg as manganese sulfate; I, 0.5 mg as potassium iodate; Se, 0.3 mg as sodium selenite. ⁴ Data are expressed as mean±standard deviation (SD), n=3. ⁵ Calculated values. All percentages are mass fractions

measured using an amino acid automatic analyzer (Hitachi L8900, Japan). These analytical processes include analysis of crude protein and amino acid in the soybean products. The contents of glycinin and trypsin inhibitor in the soybean products were measured by quantitative detection kit (purchased from Shanghai Enzyme-linked Biotechnology Co., Ltd., China). On 0 and 28 d of the experiment, pigs were weighed, and the feeds provided and remaining were recorded on a pen basis to calculate average daily gain (ADG) and average daily feed intake (ADFI). Feed conversion rate was calculated as kilograms of feed intake per gram of body weight gain and it was expressed as feed to gain ratio (F:G).

Blood samples were collected from two pigs randomly selected per pen. Blood samples (5 ml) were collected on Day 28 via jugular vein puncture into vacutainer tubes. Blood samples were centrifuged at 4 °C for 10 min at 3000g, and serum was obtained. The samples were packed in Eppendorf tubes, snap frozen in liquid nitrogen, and stored at -70 °C until measuring total protein (TP) and blood urea nitrogen (BUN) concentrations.

Fresh feces of two pigs with the same diet from each pen were collected randomly between 09:00 and 12:00 on Days 25 to 27. The feces were frozen in liquid nitrogen immediately, and then temporarily stored in the -20 °C refrigerator until analyzing the ammonia nitrogen and nitrite in feces and the fecal pH.

2.4 Determination of ammonia and particulate matter concentrations in piggery

An ammonia meter (Dräger X-am 7000 portable gas monitor) was used to determine NH₃ concentration in piggery three times daily, namely at 06:00–07:00, 12:00–13:00, 19:00–20:00, and by choosing three points in the axis of the barn at 50, 70, and 90 cm from the ground. Doors and windows of the piggery were closed at 1 h before the determination, and the monitors were placed at the three points until the data were stable to record and the mean values were taken. This study measured the mass concentrations of particulate air pollutants, PM₁₀ and PM_{2.5}, which are classified according to particle size, representing PM smaller than 10 and 2.5 μm aerodynamic diameters, respectively. A PM indexer (Hinaway CW-HAT200 Handheld Air Quality Tester, China) was used to determine directly the PM₁₀ and PM_{2.5} numerically within 0.5 h after morning feeding. Three points on the axis of the barn were chosen, 80 cm from the ground. The air quality testers were settled in the air until the data were stable to record and the mean values were taken.

2.5 Chemical analysis

TP and BUN concentrations in serum were measured using the auto-biochemical analyzer (RX Daytona™). Ammonia nitrogen in feces was measured by Nessler's reagent colorimetric method (Leonard, 1963). Nitrite in feces was determined by Griess reaction (Griess, 1879). The fecal pH was measured by pH meter according to the method described by Canh *et al.* (1998).

2.6 Statistical analysis

A completely randomized design was used in this experiment. All the data were analyzed statistically using the independent sample T-test procedure of SPSS 20.0 statistical analysis to conduct variance analysis. The pen was the experimental unit. A probability level of $P < 0.05$ was considered statistically significant.

3 Results

3.1 Nutrient composition of fresh fermented soybean meal

The crude protein content of fresh FSM was higher than that of soybean meal, and the same was the case for the concentrations of analyzed amino acids. In contrast to this, the contents of glycinin and trypsin inhibitor decreased in the fresh FSM. The nutrient composition of the soybean meal pre- and post-fermentation is shown in Table 2.

Table 2 Nutrient composition of soybean meal and fresh fermented soybean meal¹

Nutrient level (dry matter basis)	Soybean meal	FSM
CP ² (%)	46.2±1.43 ^b	58.5±1.67 ^a
Lysine (%)	2.48±0.07 ^b	3.22±0.08 ^a
Threonine (%)	1.84±0.07 ^b	2.34±0.05 ^a
Methionine+cysteine (%)	1.32±0.09 ^b	1.91±0.06 ^a
Glycinin (%)	14.06±0.39 ^a	3.77±0.06 ^b
β-Conglycinin (%)	13.13±0.16 ^a	3.21±0.03 ^b
Trypsin inhibitor (mg/g)	11.21±0.21 ^a	0.01±0.001 ^b

¹ Data are expressed as mean±SEM, $n=3$. ² CP: crude protein. ^{a,b} Means in the same row followed by different superscript letters differ significantly at $P < 0.05$. All percentages are mass fractions

3.2 Effect of fresh fermented soybean meal on growth performance of nursery piglets

Piglets were healthy with a mortality of 1.69% and 1.27% in the control and FSM groups, respectively, throughout the experiment, which was not associated with dietary treatment. There was no bacterial or viral infection during the experiment.

Pigs fed diet containing fresh FSM had increased ($P < 0.05$) ADG and ADFI. The ADG and ADFI in the FSM group increased by 13.6% and 8.7%, respec-

tively, compared with the control group. The feed to gain ratio (F:G) decreased in the FSM group, but there was no significant difference ($P > 0.05$) between experimental groups. The effect of fresh FSM on the growth performance of nursery piglets is shown in Table 3.

Table 3 Effect of fresh fermented soybean meal on the growth performance of nursery piglets¹

Group	IW (kg)	FW (kg)	ADG (g/d)	ADFI (g/d)	F:G
Control	16.3	33.0	599 ^b	1205 ^b	2.05
FSM	16.3	35.4	680 ^a	1310 ^a	1.93
SEM	1.03	1.79	30.1	28.1	0.06
<i>P</i> -value	0.95	0.22	0.02	0.004	0.19

¹ Experimental diets were: dietary inclusion of 100 g/kg fresh fermented soybean meal (FSM) in the FSM group, and no fresh FSM in diet as the control. IW: initial weight; FW: final weight; ADG: average daily gain; ADFI: average daily feed intake; F:G: feed to gain ratio; SEM: pooled standard error of the mean of two groups. ^{a,b} Means in the same column followed by different superscript letters differ significantly at $P < 0.05$

3.3 Effect of fresh fermented soybean meal on ammonia concentration in piggery

The concentration of NH₃ in the piggery was reduced significantly in the FSM group. During the first two weeks of the experiment, the concentration of NH₃ in the FSM group was reduced ($P > 0.05$) by 4.7% compared with the control group. During the third to fourth week of the experiment, the concentration of NH₃ in the FSM group declined ($P < 0.05$) by 37.6% compared with the control group. During the whole experiment, the concentration of NH₃ in the FSM group was decreased ($P < 0.05$) by 19.0% compared with the control group. The effect of fresh FSM on the concentration of NH₃ in the piggery is shown in Fig. 1.

3.4 Effect of fresh fermented soybean meal on particulate matter concentration in piggery

From the Fig. 2, it is clear that the concentrations of PM₁₀ and PM_{2.5} in piggery were reduced significantly in the FSM group. During the first two weeks of the experiment, the concentration of PM₁₀ reduced ($P < 0.05$) by 12.7% in the FSM group compared with the control group. During the third to fourth week of the experiment, the concentration of PM₁₀ declined ($P < 0.05$) by 28.2% in the FSM group compared with

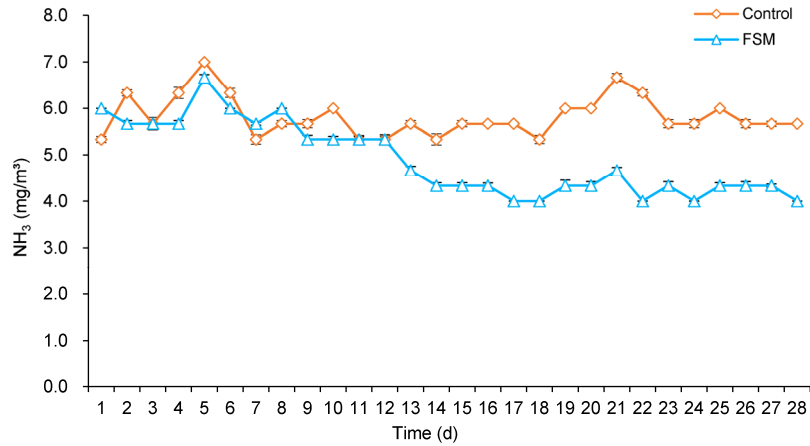


Fig. 1 Effect of fresh fermented soybean meal (FSM) on the concentration of ammonia (NH₃) in piggery during the experiment

Experimental diets were: dietary inclusion of 100 g/kg fresh FSM in the FSM group, and no fresh FSM in diet as the control. Data are expressed as mean±SEM, n=3

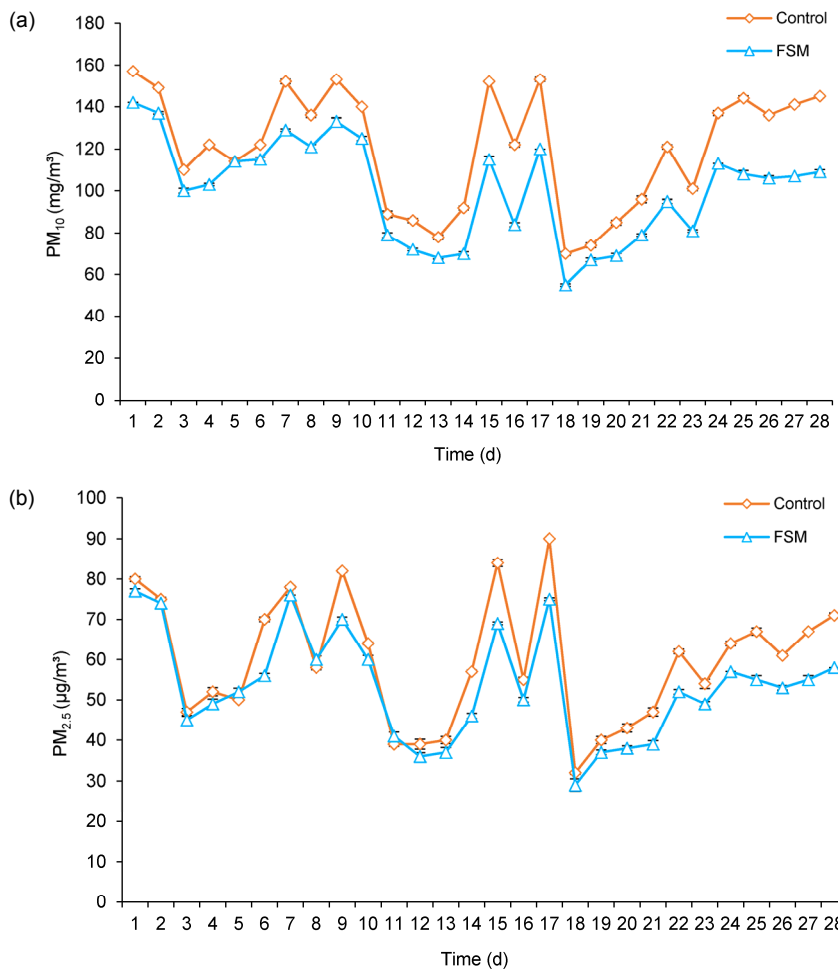


Fig. 2 Effects of fresh fermented soybean meal (FSM) on the concentrations of PM₁₀ (a) and PM_{2.5} (b) in piggery during the experiment

PM₁₀: particulate matter smaller than 10 µm aerodynamic diameters; PM_{2.5}: particulate matter smaller than 2.5 µm aerodynamic diameters. Experimental diets were: dietary inclusion of 100 g/kg fresh FSM in the FSM group, and no fresh FSM in diet as the control. Data are expressed as mean±SEM, n=3

the control group. During the whole experiment, the concentration of PM₁₀ decreased ($P<0.05$) by 19.9% in the FSM group compared with the control group. During the first two weeks of the experiment, the concentration of PM_{2.5} reduced ($P>0.05$) by 6.7% in the FSM group compared with the control group. During the third to fourth week of the experiment, the concentration of PM_{2.5} declined ($P<0.05$) by 16.9% in the FSM group compared with the control group. During the whole experiment, the concentration of PM_{2.5} decreased ($P<0.05$) by 11.6% in the FSM group compared with the control group. The effects of fresh FSM on the concentrations of PM₁₀ and PM_{2.5} in the piggery are shown in Figs. 2a and 2b, respectively.

3.5 Effects of fresh fermented soybean meal on fecal and blood indicators in nursery piglets

The ammonia nitrogen and nitrite content in feces increased ($P<0.05$) by 32.9% and 28.4%, respectively in the FSM group, compared with the control group (Table 4). Fresh FSM contained in diet reduced the fecal pH significantly. The fecal pH in the FSM group decreased ($P<0.05$) by 5.9% compared with the control group (Table 4). Fresh FSM in diet had a significant effect on some serum biochemical parameters. The TP concentration increased ($P<0.05$) by 23.6% and the BUN concentration decreased ($P<0.05$) by 10.8% in the FSM group compared with the control group (Table 4).

Table 4 Effects of fresh fermented soybean meal on fecal and blood indicators in nursery piglets¹

Group	Fecal ammonia nitrogen (g/kg)	Fecal nitrite (mg/kg)	Fecal pH	Blood TP (g/L)	BUN (mmol/L)
Control	5.93 ^b	6.83 ^b	6.93 ^a	55.2 ^b	5.34 ^a
FSM	7.88 ^a	8.77 ^a	6.52 ^b	68.3 ^a	4.82 ^b
SEM	0.32	0.44	0.04	1.68	0.14
<i>P</i> -value	<0.001	0.001	<0.001	<0.001	0.003

¹ Experimental diets were: dietary inclusion of 100 g/kg fresh fermented soybean meal (FSM) in the FSM group, and no fresh FSM in diet as the control. Determination of fecal ammonia nitrogen and nitrite content was based on dry matter. TP: total protein; BUN: blood urea nitrogen; SEM: pooled standard error of the mean of two groups. ^{a, b} Means in the same column followed by different superscript letters differ significantly at $P<0.05$

4 Discussion

In this study, dietary fresh FSM significantly improved the growth performance of nursery pigs. The present results showed that pigs fed the diet containing fresh FSM had increased ADG and improved feed utilization (reduced F:G) compared with pigs in the control group. However, the higher growth rates were, at least in part, a result of a higher feed consumption, rendering the feed efficiency to be only numerically different between groups. The results showed the improved growth performance, consistent with other studies (Jones *et al.*, 2010). Fermentation improved the bioavailability of nutrients, because of the increase in soluble protein and small peptide content, and the effective removal of anti-nutritional factors in soybean meal after fermentation (Mukherjee *et al.*, 2016). Canibe and Jensen (2003) reported that fermented liquid feed could reduce the quantity of gastrointestinal pathogens in growing pigs, maintain intestinal health, and then improve growth performance of pigs compared with dry feed.

In the present study, the diet containing fresh FSM reduced NH₃ concentration in the piggery. Ammonia emissions in the piggery are mainly generated from surplus nitrogen. Therefore, reducing dietary crude protein, which provides the basic requirement for TP intake, and supplementing with synthetic amino acids will significantly decrease NH₃ emissions (Hayes *et al.*, 2004; Cho *et al.*, 2008; Wu *et al.*, 2015). Modulating dietary composition to reduce NH₃ emission is economic and feasible, and the most important thing is that it is performed at source. In the present study, the reduction of NH₃ emissions was due to fresh fermentation of soybean meal. Mukherjee *et al.* (2016) have shown that fresh FSM contained a high proportion of small peptides and digestive enzymes, improving nutritional quality of soybean meal, increasing the utilization of dietary nitrogen, and thereby reducing the emissions of nitrogenous substances in livestock. Hobbs *et al.* (1997) reported that feeding wet material could promote protein digestion and absorption, and then reduce nitrogen emissions. The fresh FSM used in this study resulted in a decrease of nitrogen excretion, and then reduction in the concentrations of NH₃ and PM in the piggery.

Ammonia emissions in piggery are mainly generated from urea in the urine, because approximately 70% of nitrogen intake was excreted in the form of fecal nitrogen (about 20%) and urinary nitrogen (about 50%), and 80% of fecal nitrogen was in the form of organic nitrogen, with 97% of urinary nitrogen in the form of urea. Urea is easily converted to NH_3 by fecal enzyme urease, and conversely, most of the nitrogen in feces is not readily degradable (van Faassen and van Dijk, 1987). Therefore, in addition to reducing nitrogen excretion by reducing dietary protein, transferring nitrogen from the urine to the feces and then converting fecal nitrogen into bacterial protein would be an effective way to reduce nitrogen excretion, and further reducing NH_3 emissions. In the pig-breeding industry, more than 20 years ago, the method of adding microorganisms to enhance conversion of ammonia to bacterial protein was developed (Groenestein *et al.*, 1993). Aarnink and Verstegen (2007) suggested that reducing crude protein intake supplemented with fermentable carbohydrates into the diet could lessen total nitrogen excretion and transfer nitrogen from urine to feces, which could decrease NH_3 emissions in the production of growing-finishing pigs. It had been observed previously that diet supplemented with fiber reduced fecal NH_3 emissions from pig barns, because it led to the transfer of nitrogen excretion from urine to feces (Lynch *et al.*, 2008; Patráš *et al.*, 2012). Indigestible sugar had also been shown to increase transport of BUN into the large intestine for bacterial protein synthesis, and to enhance nitrogen utilization, which resulted in a significant increase in bacterial protein in the feces, with a decrease in urinary nitrogen excretion (Shriver *et al.*, 2003; Min *et al.*, 2014). Thus, it is feasible that more nitrogen being excreted via the feces in the form of bacterial protein and less from the urine as urea could reduce NH_3 emissions. In this study, there may be a higher transfer of nitrogen or urea into the gastrointestinal tract in the FSM group, which may lead to an increased fixation of nitrogen within microbial protein. This is also consistent with the results of ammonia nitrogen and nitrite content in feces as well as the blood urea content in this experiment.

PM in the piggery mainly comes from dust in the air, feed particle dust, feces and aerosol particles produced by porcine respiration and pig skin shedding. Renard *et al.* (2004) showed that bacteria and

allergens could be carried into the air by dust particles that cause infection in animals and humans. Ham-scher *et al.* (2003) suggested that antibiotics in dust originating from the farm may be a new source of human health hazards. The main factors influencing the concentration of PM in a piggery include feed type, temperature, humidity, ventilation, animal behavior, etc. (Pedersen *et al.*, 2000). Pedersen *et al.* (2000) reported on applying oil to the floors to decrease the concentration of inhalable dust. However, this method is impractical and uneconomical. In this study, the concentrations of PM_{10} and $\text{PM}_{2.5}$ in the piggery were decreased by partially replacing soybean meal with non-dried high-humidity fresh FSM. The reasons may be that the substitution of high-humidity fresh FSM increases the moisture content of feed and then reduces the production of feed dust during the feeding process. In addition, the diet containing fresh FSM had a mellow flavor, which improved the feed palatability, to a certain extent, lessening feed fight and play behaviors, while reducing the feed residue, thereby decreasing the production of feed dust in the air. Renard *et al.* (2004) reported that NH_3 could react with acid molecules in the atmosphere to form particles (by secondary conversion) that contribute to the load of PM significantly. Therefore, reduction of NH_3 emissions also contributes to the decrease of PM concentration. Several steep peaks appeared in Figs. 2a and 2b, due to the haze in Zhejiang Province, China, which was quite severe on Days 1, 7, 9, 15, and 17 during the experiment, leading to sharp increase of PM concentrations in the piggery.

In this study, the TP concentration increased and the BUN concentration decreased in the FSM group. The TP and BUN can reflect the overall metabolism of the body protein. Within a certain range, the higher the TP concentration, the greater the ability of the body to synthesize and utilize the protein. The BUN concentration is negatively related with nitrogen deposition rate and protein utilization rate, namely, the urinary nitrogen excretion is correlated positively and linearly with BUN concentration, and the urinary nitrogen excretion could be predicted by BUN concentration (Brown and Cline, 1974; Kohn *et al.*, 2005). In this study, the decrease of BUN concentration and the increase of TP concentration suggested that the pigs fed diets with fresh FSM could utilize dietary

nitrogen efficiently, as well as leading to a reduction in urinary nitrogen excretion.

In the present study, the significant increase of ammonia nitrogen and nitrite content in feces and the significant decrease of fecal pH were observed in the FSM group. The correlation between ammonia nitrogen content in feces and NH_3 emissions from feces is affected particularly by pH (Le *et al.*, 2008). The total ammonia nitrogen is the sum of NH_3 and NH_4^+ , and the amount of NH_3 is determined by the acid dissociation constant (K_a) for NH_3 and the pH (Loehr *et al.*, 1973). The lower pH inhibited conversion of NH_4^+ to NH_3 , resulting in the ammonia nitrogen content in feces being relatively high. Overall, the lower pH increased ammonia nitrogen content in feces and decreased NH_3 emissions from the feces. Nitrite is the intermediate product of ammonia conversion to nitrate. The increase of nitrite content in feces indicated that more nitrogen was retained in the feces. The increase of nitrite content was also associated with a decline of fecal pH (Murray *et al.*, 1975). The reason why the fecal pH was reduced may be that lots of beneficial bacteria such as *Lactobacillus* and *Bacillus* and large amounts of lactic acids were produced (Canibe and Jensen, 2003; Suiryanrayna and Ramana, 2015) and that these decreased the fecal pH during the fermentation. It can therefore be said that the fecal nitrogen was retained in the form of ammonia nitrogen and nitrite. In this study, the increase of ammonia nitrogen and nitrite content in feces and the decrease of BUN concentration might be caused by the conversion of urinary nitrogen to fecal nitrogen resulting from fresh FSM, thereby reducing NH_3 emissions. The increase of ammonia nitrogen and nitrite content in feces and the decrease of fecal pH and BUN concentration were consistent with the reduction of NH_3 concentration in the piggery.

5 Conclusions

The results of this study suggested that dietary fresh FSM not only improved the growth performance of nursery piglets, but also reduced the concentrations of NH_3 , PM_{10} and $\text{PM}_{2.5}$ in the piggery by an increase in microbial N-fixation and a rerouting of urea from the blood to the feces instead of the urine. Therefore, it is suggested that fresh FSM could be used to partially replace soybean meal in diets, which

would help to lower the contribution of livestock production to harmful gases and substances in the environment.

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Compliance with ethics guidelines

Sai-sai CHENG, Yuan LI, Shi-jie GENG, Luan-sha HU, Xiong-feng FU, and Xin-yan HAN declare that they have no conflict of interest.

All institutional and national guidelines for the care and use of laboratory animals were followed.

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中文概要

题目: 日粮中新鲜发酵豆粕对保育猪生长性能、氨气和颗粒物排放以及氮排泄的影响

目的: 评估日粮中新鲜发酵豆粕对仔猪生长的促进作用及对畜舍空气质量的改善作用。

创新点: 首次证实新鲜发酵豆粕的使用可提高仔猪对日粮氮的利用,降低氮排泄以及降低畜舍氨气和颗粒物浓度。

方法: 选择日龄相近的 472 头保育仔猪(长×大二元杂交,体重(16.3±0.36) kg),随机分为两组,每组 236 头。对照组饲喂不添加新鲜发酵豆粕的基础日粮,试验组饲喂添加 10%新鲜发酵豆粕的日粮(FSM 组),两组日粮的粗蛋白含量一致。试验期 28 天,试验期间监测畜舍氨气和颗粒物浓度(图 1 和 2),试验结束采样进行化学检测。

结论: 与对照组相比,FSM 组的平均日增重显著提高($P<0.05$)。在整个实验过程中,与对照组相比,FSM 组猪舍中 NH_3 浓度下降了 19.0% ($P<0.05$),颗粒物(PM_{10} 和 $\text{PM}_{2.5}$)浓度分别下降了 19.9% ($P<0.05$) 和 11.6% ($P<0.05$)。FSM 组粪便中氨态氮和亚硝酸盐含量分别增加了 32.9% ($P<0.05$) 和 28.4% ($P<0.05$)。与对照组相比,FSM 组粪便 pH 值明显下降 ($P<0.05$)。试验结束时,FSM 组的总蛋白浓度显著增加 ($P<0.05$),血清尿素氮(BUN)浓度降低 ($P<0.05$)。结果表明,日粮中新鲜发酵豆粕不仅提高了保育猪的生长性能,而且减少了粪便中氮向 NH_3 的转化,降低了畜舍中 PM_{10} 和 $\text{PM}_{2.5}$ 的浓度。

关键词: 新鲜发酵豆粕;氨气;颗粒物;氮转化;保育猪