Research Article

Efficacy of Aluminum Chloride in Pig Slurry Odor Control During Storage

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Abstract | Odor emission from animal wastes such as manure and slurry seriously affects animal health, and their environment. The control technology for odor emissions is still needed. Thus, the objective of the current study was to evaluate aluminum chloride ($AlCl_3$) as an acidifier to reduce odorous compounds from pig slurry, as well as microclimatic temperature variations and pig eye conditions in pig indoor facilities during storage. A total of 360 crossbred fattening pigs ([Landrace × Yorkshire] × Duroc]) with an average body weight of 60.5 ± 1.21 kg, were randomly divided into nine-floor pens (40 pigs/pen) in a single facility for a month. Aluminum chloride was added weekly to pig slurry pits (3.5×9.0×1.5 m) at 0, 0.05, and 0.1% $AlCl_3$ on a volumetric basis determined by the estimated final manure volume for each flush cycle. Ammonia levels were measured twice a week at 90 cm height and ammonia, hydrogen sulfide, methyl mercaptan, and dimethyl sulfide levels were measured twice a week at 10 cm height from the pig slurry pits. Over time, the addition of 0.05% and 0.1% $AlCl_3$ decreased overall ammonia and hydrogen sulfide losses and average ammonia and hydrogen sulfide levels at 10 cm height and overall ammonia losses at 90 cm height from the pig slurry pits. Methyl mercaptan and dimethyl sulfite gases were not detected at 10 cm height from the pig slurry pits. In addition, the microclimatic temperature and eye inflammation were reduced by the 0.05% and 0.1% $AlCl_3$ treatments because of the acidifying properties of $AlCl_3$. $AlCl_3$treatment is the best management practice that improves a pig-rearing environment.

Keywords | Aluminum chloride, Ammonia, Hydrogen sulfide, Pig indoor facilities, Pig slurry

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INTRODUCTION

Livestock excreta in large confinement facilities can lead to air problems such as excessive particulates, odors, and gaseous emissions (Sureshkumar *et al.*, 2022). Especially, the odors detected in these facilities are a result of incomplete fermentation or decomposition of livestock manure by bacteria under anaerobic conditions (Jang and Jung, 2018). Also, the odor emitted from livestock manure is attributable to a combination of up to 150 different compounds. For example, previous studies have identified more than 168 chemical compounds in the air in pig confinement buildings (Somagond *et al*., 2020). Furthermore, mixtures of more than 411 identified compounds and fixed gases were identified by Janni (2020) in pig facilities, and the odors from pig production were more unpleasant than those from other livestock production. The main odorous compounds include ammonia (NH_3), amines ($R\text{-}NH_2$), sulfur-containing compounds, volatile fatty acids, indoles (C_8H_7N), and skatole (C_9H_9N). In terms of best management practices (availability of mitigating techniques and economic returns), the types of additives that reduce odors from pig-house shallow pits and lagoons can be classified into 5 categories: (1) acidifiers, (2) adsorbents, (3) urease inhibitors, (4) saponins, and (5) digestive–biological additives (McCrory and Hobbs, 2001). The effect of these additives on slurries is well documented, but there has been much debate on their efficacy. Among them, acidifiers, acid-forming salts (aluminum chloride and alum) that reduce pH, are effective in reducing NH_3 emissions rather than ammonium; however, the addition of alum to swine manure increases hydrogen sulfide (H_2S) emissions (Smith *et al*., 2001). Since then, aluminum chloride ($AlCl_3$) at 0.75% was tested by Smith *et al*. (2004) and revealed a reduction in relative NH_3 losses by 52% from swine manure for the entire 6 weeks. In some cases, the extent and nature of the livestock health effects in indoor facilities will depend on the time and intensity of exposure (de Brito-Andrade *et al*., 2022). The eyes and respiratory tract sometimes show immediate symptoms after actual exposure to some odorous compounds such as volatile organic compounds, as reported by Li *et al*. (2021). Currently, there is limited information on the effects of $AlCl_3$ addition on temperature and pig health based on the levels of these gases usually found in the indoor atmosphere. Therefore, the objective of the current study was to evaluate $AlCl_3$ as an acidifier to reduce odorous compounds from pig slurry and temperature changes and pig eye conditions in pig indoor facilities during storage.

MATERIALS AND METHODS

All protocols used in this experiment were performed according to the Animal Experimental Guidelines provided by the Choi Shin Farm (Yeungcheon, South Korea) Animal Care and Use. A total of 360 crossbred fattening pigs ([Landrace × Yorkshire] × Duroc]), withan average body weight of 60.5 ± 1.21 kg, were used for the 4-week trial. The fattening pigs were fed the same commercial feed (14.5% crude protein, 0.52% Ca, and 0.49% P) during the fattening period. The pigs were housed in 9 suspended pens with slatted floors (pen size, 3.5 m×9.0 m). Each pen had a self-feeder and nipple waterer to allow *ad libitum* consumption. The housing facility was equipped with a ventilation and temperature control system and variable settings to provide appropriate environmental conditions for the fattening pigs. The randomized complete block designs to reduce odorous gases from pig slurry during storage were adopted, and it was composed of 3 treatments, 3 replicates, and 40 animals per pen. $AlCl_3 \cdot 6H_2O$ was obtained from Daejung Chemical and Metals CO (Siheung, South Korea) and added weekly to pig slurry pits at 0, 0.05, and 0.1% $AlCl_3$ (3 treatments) on a volumetric basis determined by the estimated final manure volume for each flush cycle. The pig slurry pits (3.5×9.0×1.5 m) were constructed with slatted floors. The slurry systems have deep-pit storage under the building or shallow pits with pull-plug flushing (a weekly flush cycle). Ammonia fluxes were measured twice weekly in each pen by using a multi-gas analyzer (Yes Plus LGA; Critical Environment Technologies Canada Inc., Delta, Canada) at a height of 10 cm from the pig slurry pits. In addition, NH_3 was measured twice a week at a height of 90 cm, and H_2S, methyl mercaptan, and dimethyl sulfide measurements were performed twice a week at a height of 10 cm from the pig slurry pits by using Gas-Tech (Gas Tech Corporation, Fukaya, Ayase, Japan). All odorous gases were also measured at nine random locations. The measurement periods were December 13, 17, 20, 24, 27, and 31, 2018 and January 3, 7, and 10, 2019. Fluctuations in the temperature in each pen (December 20 and 27, 2018 and January 3 and 10, 2019) were determined weekly by using a thermal imaging camera (FLIR, Nashua, USA). At the end of the experimental period, pig eye conditions were investigated.

All data were evaluated using the general linear model (GLM) procedure implemented in the statistical software package SAS (SAS Institute, 2008) with a randomized complete block design. All results were presented as mean ± SEM values. Each pen was used as an experimental unit for accessing the odorous compounds. When significant differences were detected among the treatments, Duncan's new multiple-range test was used at $P<0.05$. To compare NH_3 and H_2S fluxes as measured across the day of the flush cycle, the data were subjected to a split-plot across time by using the mixed model procedure of SAS as the random variable. The model for analysis of the modeling parameters was given by $Yij = \mu + vi + \varepsilon ij$, Where Yij = response variable, μ = the overall mean, vi = ith treatment effects, and εij = ith random error.

RESULTS AND DISCUSSION

The NH_3 emissions from $AlCl_3$-treated and untreated pig slurry as a function of time are summarized in Figure 1A, B. When $AlCl_3$ was added to the pig slurry, NH_3 emissions generated from 10 cm and 90 cm heights in the pig slurry pits were found to be significantly ($P<0.05$) reduced. In Figure 1A, except on December 17, 24, and 27, 2018, statistical significance was observed in the $AlCl_3$ treatment groups ($P<0.05$) during the experimental periods. With time, the NH_3 levels in the controls were higher than those in the other treatments. In the $AlCl_3$ treatments, overall NH_3 losses at 10 cm height from the pig slurry pits decreased over time by 21.9-43.4% and 22.7-55.0% when $AlCl_3$ was used at rates of 0.05% and 0.1%, respectively. The NH_3 levels measured on December 17, 2018 were not statistically significant (Figure 1B); however, during the experiment periods, significant differences were observed in all the treatments ($P<0.05$). NH_3 in the control ranged from 89 ppm to 115 ppm when compared with the other treatments (50 ppm to 80 ppm over time). The NH_3 levels measured at 90 cm height from the pig slurry pits were higher than those measured at 10 cm height. This reflected the typical characteristics of NH_3, which means that NH_3 generated from the pig slurry pits volatilizes and diffuses into the atmosphere. The data obtained at 90 cm height from the pig slurry pits showed overall reductions in NH_3 concentrations for 0.05% and 0.1% $AlCl_3$ treatments as a function of time of 10.3 to 53.8% and 15.4 to 50.0%, respectively. Our data on lower NH_3 levels obtained by $AlCl_3$ addition are almost similar to that obtained by Smith *et al.* (2004). The reason for the $AlCl_3$ treatments reducing NH_3 generated from the pig slurry can be explained by the acidifying properties of $AlCl_3$. When $AlCl_3$ was added to swine manure, foam formed on the surface. However, this was not observed in our study. These differences have been associated with the concentrations of $AlCl_3$ used in this study.

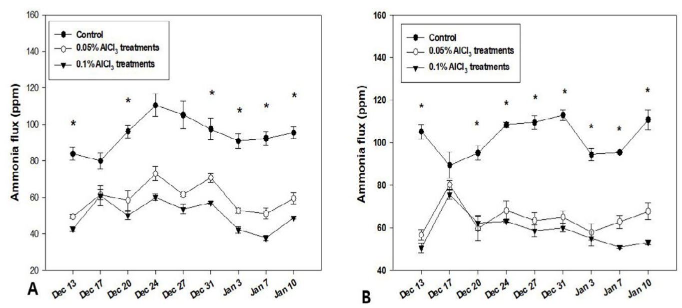

Figure 1: Effects of different rates of aluminum chloride on ammonia at 10 cm height (A) and 90 cm height (B) in pig slurry pits as a function of time (Dec 20, 2018 to Jan 10, 2019). * Indicates significant differences at $P < 0.05$.

The H_2S emissions from $AlCl_3$-treated and untreated pig slurry over time are presented in Figure 2. The H_2S emissions measured at 10 cm from the pig slurry pits were significantly reduced ($P<0.05$) by two different $AlCl_3$ treatments when compared with the controls measured from December 13, 2018 to January 10, 2019, but not December 17, 20, 24, and 27, 2018. In Figure 2, changes in 0.05% or 0.1% $AlCl_3$ treatments on December 13 to 24, 2018 resulted in a reduction in H_2S emissions by 26.9% to 42.0% or 32.8% to 50.7%, respectively. Especially, from December 31, 2018 to January 10, 2019, 0.05% $AlCl_3$treatments (ranging from 2.28 ppm to 2.33 ppm) reduced H_2S concentration by about 56.0 to 58.0% when compared with the control. Likewise, 0.1% $AlCl_3$treatments that ranged from 0.56 ppm to 2.11 ppm had an H_2S reduction rate of 78.0 to 90.0%. In general, H_2S is colorless gas emitted during the decomposition of pig manure or slurry and has the characteristic odor of rotten eggs at low concentrations (Hu *et al.*, 2017; Chen *et al.*, 2021). Our study showed that H_2S concentrations are usually very low in pig housing when compared with NH_3 concentrations. The reduction in H_2S may be due to the increase in acidification by $AlCl_3$ addition.

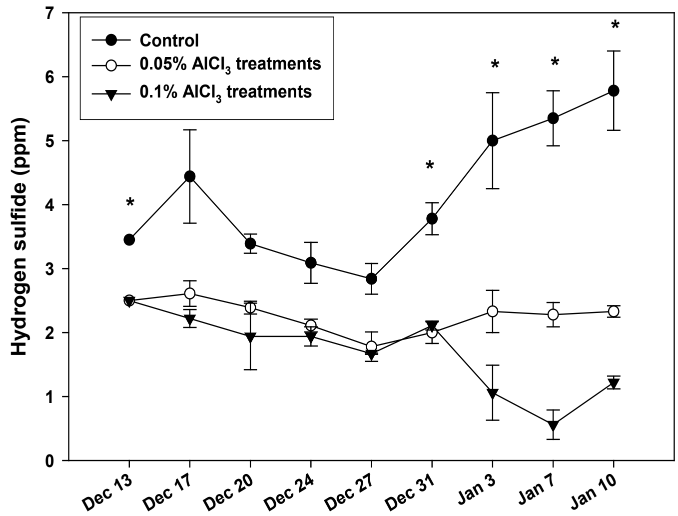

Figure 2: Effects of different rates of aluminum chloride on hydrogen sulfide at 10 cm height in pig slurry pits as a function of time (Dec 20, 2018 to Jan 10, 2019). * Indicates significant differences at $P<0.05$.

Table 1: Effects of different rates of aluminum chloride on average ammonia, hydrogen sulfide, methyl mercaptan, and dimethyl sulfide at 10 cm height in pig slurry pits in 4 weeks.

Item (ppm)	Treatment			p value
	Control	0.05% $AlCl_3$ treatments	0.1% $AlCl_3$ treatments	
Ammonia	93.22 ± 3.14^{1a}	59.80 ± 2.92^{b}	50.37 ± 2.93^{b}	$P< 0.0001$
Hydrogen sulfide	4.12 ± 0.37^{a}	2.26 ± 0.09^{b}	1.69 ± 0.22^{b}	$P< 0.0001$
Methyl mercaptan	ND[2]	ND	ND	-
Dimethyl sulfide	ND	ND	ND	-

[a-c]Means in the same row with different superscripts differ significantly ($P<0.05$). [1]Values are expressed as means±standard errors. [2]NS: not detected.

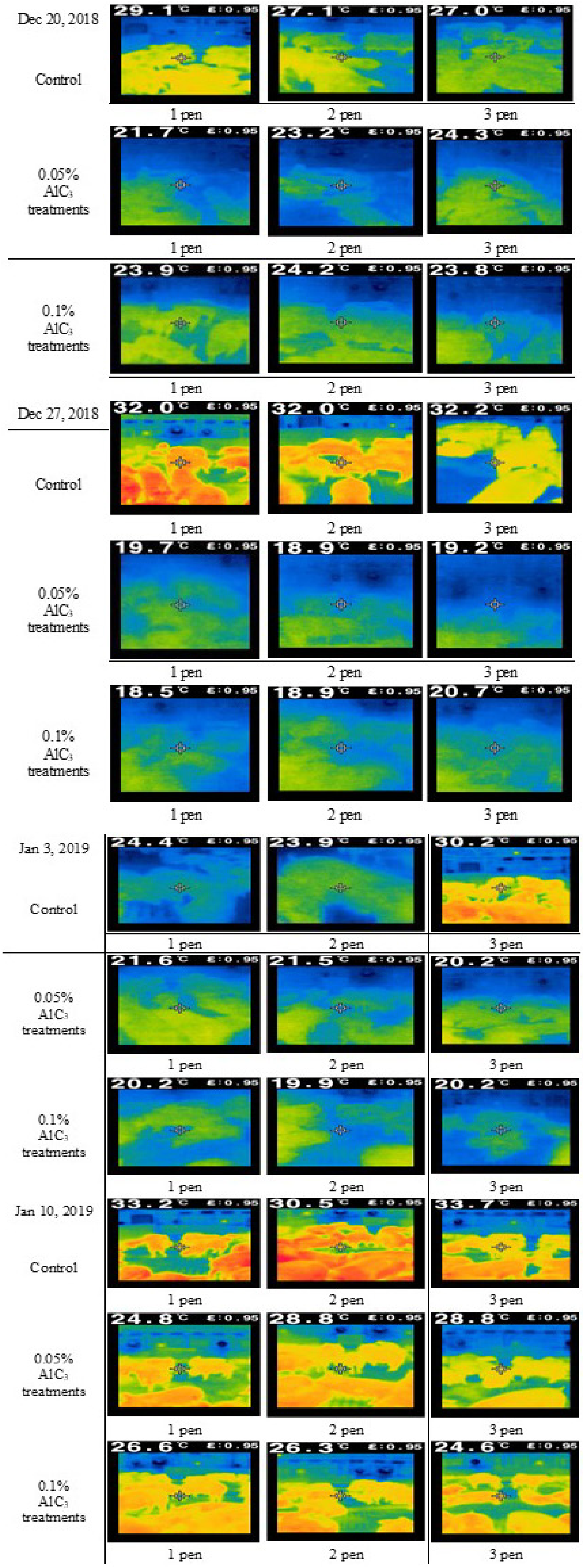

Figure 3: Temperature changes in pig slurry pits treated with different rates of aluminum chloride during the experimental period.

Table 1 showed the average values of NH_3, H_2S, methyl mercaptan, and dimethyl sulfite measured for four weeks at 10 cm from the pig slurry pits when $AlCl_3$ was added to the pig slurry. The methyl mercaptan and dimethyl sulfite gases were not detected in the pig slurry pits because our results were measured in ppm rather than ppb. The NH_3 levels showed an average reduction ($P<0.05$) of 35.9 and 46.0% for 0.05% and 0.1% $AlCl_3$ treatments, respectively, in four weeks. The average H_2S levels were reduced ($P<0.05$) by 45.0 and 58.9% after the 0.05% and 0.1% $AlCl_3$ treatments, respectively. The 0.1% $AlCl_3$ treatment tended to decrease either NH_3 or H_2S levels or average NH_3 and H_2S levels measured at 10 cm from the pig slurry pits to a greater extent than 0.05% $AlCl_3$ treatment. The results indicated that changing the acidity of pig slurry can result in biochemical changes that reduce the formation of certain gases. In other words, acidity is used to create less favorable conditions for the bacteria and enzymes that contribute to NH_3 and H_2S formation during storage (Overmeyer *et al*., 2021).

The temperature changes measured weekly in the pig slurry pits decreased because of the two different $AlCl_3$ treatments (Figure 3). Mohammed-Nour (2019) indicated that the importance of factors that affect NH_3 volatilization was as follows: pH, temperature and moisture content. Thus, the main abilities of acidifiers to reduce NH_3 content in animal wastes are associated with lower pH (Smith *et al*., 2004; McIlroy *et al*., 2019). Our results suggested that the relative NH_3 and H_2S losses were significantly related to decreasing temperature in the pig housing. In winter, indoor air quality is very important and minimal fluctuations in temperature or an increase in temperature can adversely affect the air quality as ventilation is restricted (Febrisiantosa *et al*., 2020). This was well demonstrated in the present study (Figure 3).

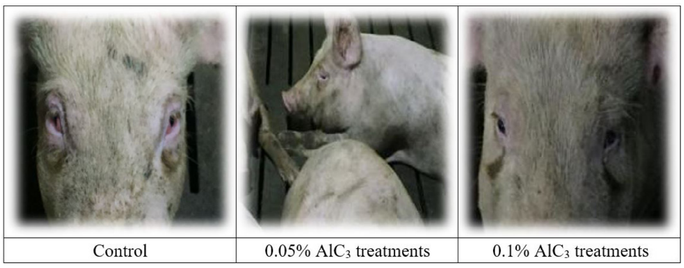

Figure 4: Eye views of pigs affected by different rates of aluminum chloride in pig facilities.

Eye views of pigs in the facilities are shown in Figure 4. In the current study, decreased inflamed eyes of the pig might be explained by the result from two different rates of treatments because of their ability to reduce NH_3 and H_2S losses and, in turn, atmospheric NH_3 and H_2S levels, within the pig facilities. For example, exposure to a high level of NH_3 and even a low concentration of H_2S in pig housing irritate the eyes, nose, and throat and cause coughing and difficulties in breathing.

CONCLUSIONS AND RECOMMENDATIONS

The 0.05% and 0.1% $AlCl_3$ treatments of pig slurry reduced either NH_3 or H_2S emission measured weekly or average NH_3 and H_2S levels in four weeks at 10 cm height from the pig slurry pits, including NH_3 levels measured at 90 cm height from the pig slurry pits. Methyl mercaptan and dimethyl sulfite gases were not detected in the pig slurry because our results were measured in ppm (not ppb). The 0.1% $AlCl_3$ treatment tended to decrease NH_3 and H_2S levels measured at 10 cm from the pig slurry pits (in some cases, NH_3 levels measured at 90 cm height) to a greater extent than the 0.05% $AlCl_3$ treatment. The other abilities of $AlCl_3$as an acidifier to reduce NH_3 and H_2S levels from pig slurry were associated with reducing the temperature within pig housing. In addition, the two different treatments caused a decrease in pig eye inflammation because of the reduction in NH_3 and H_2S losses and, in turn, atmospheric NH_3 and H_2S levels within pig facilities. Hence, the addition of $AlCl_3$ to pig slurry can be considered an effective or selective alternative for reducing several odorous compounds in a pig-rearing environment.

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NOVELTY STATEMENT

The current study evaluated $AlCl_3$ as an acidifier to reduce odorous compounds from pig slurry and temperature changes and pig eye conditions in pig indoor facilities during storage.

AUTHOR'S CONTRIBUTION

Chang-Man Kim: Conceptualization and Methodology.
Young-Ho Joo: Methodology and Data analysis.
Sam-Churl Kim: Data analysis, Editing and Writing.
In-Hag Choi: Conceptualization, Editing, Supervision and Writing

Conflict of interest
The authors have declared no conflict of interest.

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