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Dietary manipulation to reduce aerial ammonia concentrations in nursery pig facilities[1,2]

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ABSTRACT: Two 4-wk trials (preliminary study) and three 5-wk trials (major study) were conducted to determine the effects of adding *Yucca schidigera* extract or anhydrous calcium chloride to nursery diets on the growth performance of nursery pigs and aerial ammonia concentration. The pigs were weaned between 13 and 15 d of age and had an initial BW of 3 to 6 kg. In each trial, pigs were allotted to three identical pig nursery rooms that were environmentally regulated. There were three diets (one diet per room): 1) control, containing 23% CP; 2) control plus 125 ppm of *Yucca schidigera* extract; and 3) control plus 1.95% anhydrous calcium chloride. Growth performance was recorded weekly. Aerial ammonia concentration was measured daily using aspiration detector tubes and during the last week of each trial using diffusion tubes. Manure samples were collected twice a week during the experimental period to determine ammonia and N concentrations and pH. Plasma urea concentration was determined in blood samples collected from the pigs at the end of each trial. Data were analyzed using split-plot and Latin square designs for the preliminary and major studies, respectively. Feed intake was similar among pigs fed all three diets. There were no differences in ADG and ADG/ADFI (G/F) between pigs fed the control diet and pigs fed the yucca extract diet ($P \geq 0.41$). In all trials, pigs fed the calcium chloride diet had lower ADG and G/F than pigs fed the other two diets ($P < 0.05$). In the preliminary study, aerial ammonia tended to be greater in the rooms in which pigs were fed the control diet than in the rooms with pigs fed the yucca extract diet ($P = 0.08$) and the calcium chloride diet ($P = 0.11$). In the major study, aerial ammonia increased weekly (diet × week; $P < 0.001$) in all rooms. In the 4th wk, ammonia concentrations were greater ($P < 0.001$) in the rooms in which pigs were fed the control diet than in the rooms in which the other two diets were fed. Dietary treatment had no effect on plasma urea concentration ($P \geq 0.10$), manure ammonia and N concentrations ($P \geq 0.50$), and manure pH ($P \geq 0.78$). Although aerial ammonia concentrations were relatively low, the addition of *Yucca schidigera* extract or calcium chloride to the diet of nursery pigs reduced ammonia concentrations in the nursery rooms.

Key Words: Ammonia, Calcium Chloride, Growth, Pig Manure, Pigs, Yucca Schidigera

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Introduction

Ammonia concentrations in and emissions from swine facilities are matters of public concern because of the possibility of negative health effects in both humans and animals and the association of ammonia emission with odor near swine facilities.

In growing-finishing pigs, several experiments have investigated the addition of special dietary ingredients as a means of reducing aerial ammonia concentration and emission. Ammonia emission has been reduced by adding yucca extract to the diet (Morel, 1997; Cole et al., 1998; Cromwell et al., 1999). Another approach has been to add acidifying salts. The addition of acidifying salts, such as calcium chloride, has reduced ammonia emission from pig manure by 33% (Canh et al., 1998). Most of the research has either been conducted on large swine farms with little or no control of environmental conditions or has involved in vitro release of ammonia from manure samples collected from pigs in metabolism cages.

Ammonia emission by nursery pigs has been largely ignored until recently (Whitney et al., 1999; van Zeeland et al., 2000) probably because the output of feces and urine is relatively low. However, nursery pigs require diets with high amino acid concentrations (NRC,

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Table 1. Details of the five trials

Trial	Duration, wk[a]	Pigs per pen (barrows, gilts)[b]	Weaning age, d	Weaning weight, kg	Breed[c]
1	1 + 3	6, 0	15	5.2	¼Y, ⅜LR, ⅜LW
2	1 + 3	6, 4	13	3.0	⅛LW, ⅛H, ⅜LR, ⅜D
3	1 + 4	7, 3	14	3.5	⅛LW, ⅛H, ⅜LR, ⅜D
4	1 + 4	6, 4	15	5.9	⅛H, ⅜D, ½LW
5	1 + 4	5, 5	14	4.8	¼LW, ¼Y, ⅛H, ⅜D

[a]Each trial consisted of a 1-wk initial period followed by a 3- or 4-wk experimental period.
[b]Each room contained five pens: 0.62 m^2/pig (Trial 1) and 0.37 m^2/pig (Trials 2, 3, 4, and 5).
[c]Y = Yorkshire, LR = Landrace, LW = Large White, H = Hampshire, and D = Duroc.

1998), and any excess protein will contribute to urea formation, which may be hydrolyzed to ammonia by urease present in feed and manure (Aarnink et al., 1998). Also, ammonia concentrations in nursery rooms may be high because of reduced ventilation rates in an attempt to conserve heat when outside temperatures are low.

The objective of this research was to determine whether the dietary addition of *Yucca schidigera* extract and calcium chloride affects ammonia production and(or) release by nursery pigs or their manure and consequently ammonia concentrations in nursery pig facilities. To do this, we made direct measurements of aerial ammonia concentrations in research nursery rooms in which temperature, humidity, and ventilation were carefully controlled.

Materials and Methods

Experimental Procedures

This research consisted of five trials: two 4-wk trials (preliminary study) and three 5-wk trials (major study). Information about each trial is presented in Table 1. The pigs were weaned between 13 and 15 d of age and had an initial BW of 3 to 6 kg. In all trials, pigs were blocked on initial weight and allotted to one of three environmentally controlled rooms such that the average initial weight within each room was similar. Housing conditions, dietary treatments, and all measurements were the same in all trials, except that N concentration in manure slurry was determined only in the three 5-wk trials.

Housing. Three identical pig nursery rooms that were environmentally regulated were used. Each room was 7.3 m long × 4.2 m wide × 5.4 m high and had five pens. Each pen was 1.7 m long × 2.2 m wide × 0.9 m high with vertical-rod gating and had plastic-coated wire flooring, one nipple waterer, and one three-hole stainless steel feeder. Pigs had ad libitum access to feed and water throughout the trials. Heat lamps and comfort boards were provided during the 1st wk after weaning. There was no natural daylight, and fluorescent lighting was on at all times. In each room, relative humidity (maintained at 60%) and temperature (maintained at 25°C) were monitored continuously using temperature and humidity recorders. The amount of air brought into and out of each room (maintained at 26 m^3/min) was measured twice daily (0800 and 1400) in the exhaust duct with a portable air velocity meter (Kurz Series 440; Model 4419; Monterey, CA) equipped with a hot-wire anemometer.

Manure (feces, urine, spilled feed, and spilled drinking water) that collected below the pens was allowed to accumulate throughout the trials. Manure that drained from the pens was maintained in a collection pit located at the end of each room. These pits were emptied weekly because their capacity was limited. Water was not added when pits were emptied.

Dietary Treatments. During the 1st wk of each trial, all pigs were fed the same commercial prestarter diet (23.5% CP, 1.75% lysine, 0.75% Ca, and 0.70% P, with 165 mg/kg apramycin sulfate) to allow them to adapt to the initial stress of weaning. For the next 3 wk (Trials 1 and 2) or 4 wk (Trials 3 to 5), three experimental diets were fed. All diets were formulated to meet or exceed the nutrient requirements of nursery pigs (NRC, 1998). Diets (Table 2) fed were 1) control, 2) control plus 125 ppm of *Yucca schidigera* extract (De-Odorase, Alltech, Nicholasville, KY), and 3) control plus 1.95% anhydrous calcium chloride. The *Yucca schidigera* extract consisted primarily of glyco-components obtained by countercurrent elution and concentration using molecular sieves. The amount of *Yucca schidigera* extract added was that recommended by the manufacturer for nursery pigs, and the amount of calcium chloride was to adjust the dietary electrolyte balance to approximately zero. Diet samples (collected when feed was mixed) were ground through a 1-mm screen before analysis. Samples were analyzed in duplicate for DM, CP, Ca, and P according to AOAC (1990) procedures.

Measurements. Pigs were weighed and feed intakes were measured weekly to determine ADG, ADFI, and feed efficiency, expressed as gain/feed (**G/F**).

Aerial ammonia concentration was measured once daily at 0800 by using Sensidyne aspiration tubes (Sensidyne Gas Sampling System, Gastec, Japan; low-range, 0.5 to 78 ppm, No. 3L). Air was sampled in the center of the room approximately 1 m above floor level inside the pens, taking samples from the left and right side of the rooms on alternate days. Ammonia was also measured using 8-h Dräger diffusion tubes (Röhrchen

Table 2. Composition of diets[a]

Item	Control	*Yucca schidigera*	Calcium chloride
Ingredient, %			
Corn	30.43	30.42	28.48
Soybean meal (46.5% CP)	20.50	20.50	20.50
Dried whey	30.00	30.00	30.00
Spray-dried plasma protein	6.00	6.00	6.00
Menhaden fishmeal	5.00	5.00	5.00
Corn oil	5.00	5.00	5.00
Dicalcium phosphate	1.55	1.55	1.55
Vitamin premix[b]	1.00	1.00	1.00
Trace mineral premix[c]	0.10	0.10	0.10
Zinc oxide (72% zinc)	0.42	0.42	0.42
Yucca schidigera extract[d]	—	0.013	—
Calcium choride, anhydrous[e]	—	—	1.95
Nutrient composition			
Dry matter, %[f]	90.86	90.62	90.26
Crude protein, %[f]	23.22	23.22	23.00
Lysine, %[g]	1.58	1.58	1.58
Calcium, %[f]	1.13	1.13	1.65
Phosphorus, %[f]	0.95	0.93	0.96
dEB, mEq/kg[gh]	343	343	−7

[a]As-fed basis.
[b]Supplied per kilogram of diet: retinyl acetate, 4,400 IU; cholecalciferol, 550 IU; all-*rac*-α-tocopheryl acetate, 22 IU; menadione (as menadione sodium bisulfite complex), 3.3 mg; riboflavin, 5.5 mg; D-pantothenic acid (as D-calcium pantothenate), 22 mg; niacin, 33 mg; choline (as choline chloride), 110 mg; and cyanocobalamin, 22 µg.
[c]Supplied (mg/kg of diet): Cu (as $CuSO_4{\cdot}5H_2O$), 11; I (as $Ca(IO_3)_2{\cdot}H_2O$), 0.22; Fe (as $FeSO_4{\cdot}H_2O$), 110; Mn (as MnO), 22; Se (as Na_2SeO_3), 0.3; and Zn (as ZnO), 110.
[d]*Yucca schidigera* extract added at the rate of 125 ppm (De-Odorase, [30%], Alltech, Nicholasville, KY).
[e]Calcium chloride, anhydrous (36.1% Ca; 63.9% Cl).
[f]Analyzed composition.
[g]Calculated composition.
[h]dEB (dietary electrolyte balance) = Na + K − Cl.

Ammonia 20/a-D; Dräger Sicherheitstechnik GmbH, Germany) distributed throughout each room at approximately 0.5 m above the floor, three times during the last week of each trial. Five tubes were used per room to measure differences in ammonia concentration in different places in the rooms. Measurements were made on d 23 (1400 to 2200), 25 (2200 to 0600), and 28 (0600 to 1400) of the experimental period during the preliminary study and on d 28 (1400 to 2200), 31 (2200 to 0600), and 34 (0600 to 1400) of the experimental period during the major study.

Manure samples were taken from the collection pits in each room twice a week at 0830 (after aerial ammonia sampling) during the experimental period to determine pH and ammonia and N concentrations. The manure in the pits was mixed before sampling. Samples were maintained at room temperature until analysis in the laboratory within 4 h of sampling. An electrode of a laboratory pH meter was placed in the manure to determine pH. Ammonia concentration in manure was measured using an ammonia-gas detecting electrode (Orion Model 720A ISE; Thermo Orion, Beverly, MA) and procedures described by Byrne and Power (1974). Nitrogen in manure was measured by the Kjeldahl method.

Blood samples from the jugular vein were collected from each pig between 0900 and 1100 at the end of each trial. Samples were collected in heparinized evacuated tubes (10 mL) and put in ice until centrifugation. Plasma was separated and stored at −20°C until it was analyzed for urea concentration by the automated procedure of Marsh et al. (1965).

Statistical Analysis

Preliminary Study. The two preliminary trials were designed to determine how high the aerial ammonia concentration would reach in our controlled research setting. Because treatments were applied to the whole room of pigs, room was considered the experimental unit. An initial statistical analysis indicated that there were no diet × week interactions ($P > 0.40$) for any of the variables studied. Therefore, data were analyzed as a split plot in time using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC). For variables with two or more measurements within a week, such as ammonia concentration and pH in the manure slurry and aerial ammonia measured by aspiration tubes, an overall mean was calculated by week and this mean was used for the analysis. All least squares means comparisons were performed using a pairwise t-test, at $P < 0.05$. The following model was used:

$$Y_{ijk} = \mu + T_i + D_j + (T \times D)_{ij} + W_k + E_{ijk}$$

Table 3. Effect of diet on growth performance and plasma urea concentrations during the preliminary study (Trials 1[a] and 2[b])

Item	Control	*Yucca schidigera*	Calcium chloride	SEM[c]	*P*-value[d]
ADG, g	348[e]	348[e]	257[f]	8.8	0.03
ADFI, g	505	526	469	19.7	0.32
ADG/ADFI, g/kg	687[e]	660[e]	530[f]	18.3	0.04
Urea, mg/100 mL	35.7[g]	35.6[g]	29.4[h]	1.20	0.10

[a]Five pens with six barrows per pen. Average initial and final BW were 5.20 and 14.27 kg, respectively; 28-d experiment; 21-d experimental diets.
[b]Five pens with ten pigs (six barrows and four gilts) per pen. Average initial and final BW were 3.00 and 9.24 kg, respectively; 28-d experiment; 21-d experimental diets.
[c]Standard error of the mean (n = 2).
[d]Significance of the main effect of diet.
[e,f]Within a row, means without a common superscript letter differ ($P < 0.05$).
[g,h]Within a row, means without a common superscript letter tend to differ ($P < 0.07$).

where Y_{ijk} = observation on the ith trial, jth room, and kth diet; μ = overall mean; T_i = Trial 1, 2; D_j = Diet 1, 2, 3; $(T \times D)_{ij}$ = whole-plot error; W_k = wk 1, 2, 3; and E_{ijk} = error.

Data for the variables measured in the last week of each trial, such as aerial ammonia measured by diffusion tubes and plasma urea concentrations, were analyzed as a completely randomized design using tubes or pigs as subsampling. The mean of the three-times measurements for aerial ammonia (five tubes per time) was used for the analysis. The following model was used:

$$Y_{ijk} = \mu + T_i + R_j + E1_{ij} + D_k + E2_{ijk}$$

where Y_{ijk} = observation on the ith trial, jth room, and kth diet; μ = overall mean; T_i = Trial 1, 2; R_j = Room 1, 2, 3; D_k = Diet 1, 2, 3; $E1_{ij}$ = random component (error) explaining variation among experimental units on the same treatment; and $E2_{ijk}$ = random component (error) explaining variation among subsamples on the same experimental unit.

Major Study. Data were analyzed using PROC MIXED of SAS. Room was considered the experimental unit for all traits. The three trials, three rooms, and three dietary treatments constituted a Latin square design such that each treatment was assigned in turn to each room. Trial and room were blocked as rows and columns, with the interaction of trial × room × diet as the whole-plot error and week as a repeated measurement for all variables. Plasma urea concentrations and ammonia concentrations measured by diffusion tubes were analyzed using the model described for the preliminary study. For the variables with two or more measurements within a week, such as ammonia and N concentrations and pH in the manure slurry and aerial ammonia measured by aspiration tubes, an overall mean was calculated by week and this mean was used for the analysis. Means were separated as indicated for the preliminary study. The following model was used:

$$Y_{ijkl} = \mu + T_i + R_j + D_k + (T \times R \times D)_{ijk} + W_l + E_{ijkl}$$

where Y_{ijkl} = observation on the ith trial, jth room, kth diet, and lth week; μ = overall mean; T_i = Trial 1, 2, 3; R_j = Room 1, 2, 3; D_k = Diet 1, 2, 3; $(T \times R \times D)_{ijk}$ = whole-plot error; W_l = wk 1, 2, 3, 4; and E_{ijkl} = error.

Results

Preliminary Study

There were no differences ($P = 0.32$) in ADFI among pigs fed any of the three diets (Table 3). There were also no differences ($P \geq 0.41$) in ADG and G/F of pigs fed the control diet and the diet containing yucca extract. However, ADG and G/F of pigs fed the calcium chloride diet were lower ($P < 0.05$) than those of pigs fed the two other diets.

Plasma urea concentrations did not differ ($P = 0.96$) between pigs fed the control diet and the yucca extract diet (Table 3). However, pigs fed the calcium chloride diet tended to have lower ($P < 0.07$) plasma urea concentrations than pigs fed the two other diets.

Dietary treatments did not have an overall effect ($P \geq 0.13$) on aerial ammonia measured by either aspiration or diffusion tubes (Table 4). But the aspiration tubes indicated a tendency toward higher aerial ammonia in rooms with pigs fed the control diet than in rooms with pigs fed the yucca extract diet ($P = 0.08$) or the calcium chloride diet ($P = 0.11$).

Dietary treatment had no effect ($P \geq 0.50$) on ammonia concentration or pH of manure slurry (Table 4).

Major Study

There were no differences ($P = 0.46$) in ADFI among pigs fed any of the three diets (Table 5). There were also no differences ($P \geq 0.54$) in ADG and G/F between pigs fed the control diet and pigs fed the diet containing yucca extract. There was a reduction ($P < 0.05$) in ADG and G/F of pigs fed the calcium chloride diet compared with pigs fed the other two diets. For G/F, there was a diet × week interaction ($P < 0.01$; Figure 1). Treatment differences were evident during wk 1 ($P < 0.001$), 2 ($P < 0.01$), and 3 ($P < 0.06$), but not during wk 4 ($P = 0.82$).

Table 4. Effect of diet on aerial ammonia concentrations and manure characteristics during the preliminary study (Trials 1[a] and 2[b])

Item	Control	*Yucca schidigera*	Calcium chloride	SEM[c]	*P*-value[d]
Aerial NH_3, ppm (aspiration tubes)[e]	3.6[g]	2.8[h]	2.9[h]	0.16	0.13
Aerial NH_3, ppm (diffusion tubes)[f]	8.2	5.7	7.4	2.02	0.71
Manure NH_3, ppm	588	751	636	83.2	0.50
Manure pH	7.1	7.1	7.1	0.10	0.94

[a]Five pens with six barrows per pen. Average initial and final BW were 5.20 and 14.27 kg, respectively; 28-d experiment; 21-d experimental diets.
[b]Five pens with ten pigs (six barrows and four gilts) per pen. Average initial and final BW were 3.00 and 9.24 kg, respectively; 28-d experiment; 21-d experimental diets.
[c]Standard error of the mean (n = 2).
[d]Significance of the main effect of diet.
[e]Aerial ammonia concentration measured with aspiration tubes (a point-in-time value). Measurements were made daily at 0800 throughout the experimental period.
[f]Aerial ammonia concentration measured with diffusion tubes (8-h time period). Measurements were made three times during the last week of the experiment.
[g,h]Within a row, means without a common superscript letter tend to differ ($P = 0.08$) for yucca extract and ($P = 0.11$) for calcium chloride with respect to control.

There were no differences ($P = 0.41$) in plasma urea concentration among pigs fed the three dietary treatments (Table 5).

There was no effect ($P = 0.35$) of diet on aerial ammonia measured by diffusion tubes (Table 6). Aerial ammonia concentrations measured by aspiration tubes increased weekly ($P < 0.001$) in all rooms (Figure 2). There was a diet × week interaction ($P < 0.001$), with a greater increase of aerial ammonia in rooms with pigs fed the control diet than in the other rooms. Differences among treatments tended to be evident during the 3rd wk ($P = 0.07$) and were clearly evident during the 4th wk ($P < 0.001$), when ammonia concentration was 2.5 and 2.7 ppm higher in rooms with pigs fed the control diet than in rooms with pigs fed the yucca extract and the calcium chloride diets, respectively.

The effect of diet on ammonia concentration, N concentration, or pH of manure slurry was not significant ($P \geq 0.50$) in this study (Table 6).

Discussion

The results of the present study indicate that addition of yucca extract to the diet did not affect growth performance of nursery pigs. This finding is consistent with the reports of several experiments conducted with growing-finishing pigs (Amon et al., 1995; Morel, 1997; Van den Berghel et al., 2000). In contrast, Mader and Brumm (1987), Duffy and Brooks (1998), and Cole et al. (1998) have reported positive effects on growth traits when yucca extract was added to pig diets. The benefits have generally been attributed to improvements in health status of the pigs.

The reduced ADG and G/F of pigs fed the diet containing calcium chloride was probably associated with metabolic acidosis. Yen et al. (1981) reported that the addition of 4% calcium chloride (dihydrate) to the diet increased plasma chloride concentration and reduced blood pH, bicarbonate, total carbon dioxide, and base

Table 5. Effect of diet on growth performance and plasma urea concentrations during the major study (Trials 3,[a] 4,[b] and 5[c])

Item	Control	*Yucca schidigera*	Calcium chloride	SEM[d]	*P*-value[e]
ADG, g	440[g]	439[g]	333[h]	10.6	0.03
ADFI, g	620	609	552	33.4	0.46
ADG/ADFI, g/kg[f]	718[g]	737[g]	587[h]	18.8	0.05
Urea, mg/100 mL	29.3	27.7	26.5	1.17	0.41

[a]Five pens with ten pigs (seven barrows and three gilts) per pen. Average initial and final BW were 3.50 and 15.27 kg, respectively; 35-d experiment; 28-d experimental diets.
[b]Five pens with ten pigs (six barrows and four gilts) per pen. Average initial and final BW were 5.90 and 18.85 kg, respectively; 35-d experiment; 28-d experimental diets.
[c]Five pens with ten pigs (five barrows and five gilts) per pen. Average initial and final BW were 4.80 and 17.44 kg, respectively; 35-d experiment; 28-d experimental diets.
[d]Standard error of the mean (n = 3).
[e]Significance of the main effect of diet.
[f]Diet × week interaction ($P < 0.01$).
[g,h]Within a row, means without a common superscript letter differ ($P < 0.05$).

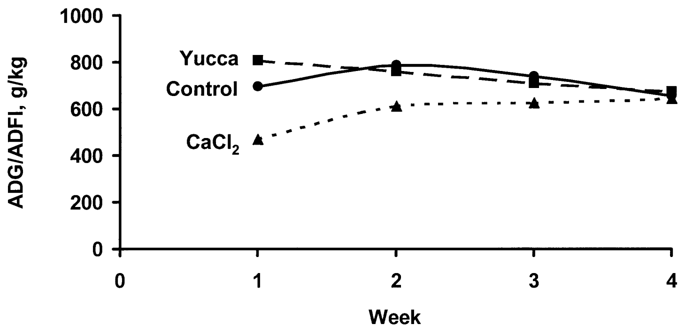

Figure 1. Feed efficiency (ADG/ADFI) by week of pigs fed control, *Yucca schidigera* extract, or calcium chloride diets in the major study (Trials 3, 4, and 5); diet × week interaction, wk 1 ($P < 0.001$), wk 2 ($P < 0.01$), wk 3 ($P < 0.06$), and wk 4 ($P = 0.82$). SEM = 33.

excess. Large additions of calcium chloride generally decrease feed intake and weight gain. Although feed intake was not significantly reduced in our experiments, the ADFI of pigs fed the calcium chloride diet was 9% less than that of pigs fed the two other diets in the preliminary study and 10% less in the major study. The dietary electrolyte balance in the calcium chloride diet was –7 mEq/kg. Patience et al. (1987) reported decreased performance in growing pigs fed a diet containing –85 mEq/kg dietary electrolyte balance. Apparently, the concentration of calcium chloride used in our study reduced the growth performance of nursery pigs.

Aerial ammonia concentrations in our nursery facilities were relatively low but were similar to concentrations measured in commercial nursery buildings (Dewey et al., 2000). The low concentrations were probably a consequence of the small size and low body weight of the pigs and the high ventilation rate. Our ventilation rate of 26 m^3/min was equivalent to 0.52 $m^3 \cdot min^{-1} \cdot pig^{-1}$ in Trials 2 to 5. This rate was much higher than the minimum rate of 0.06 $m^3 \cdot min^{-1} \cdot pig^{-1}$

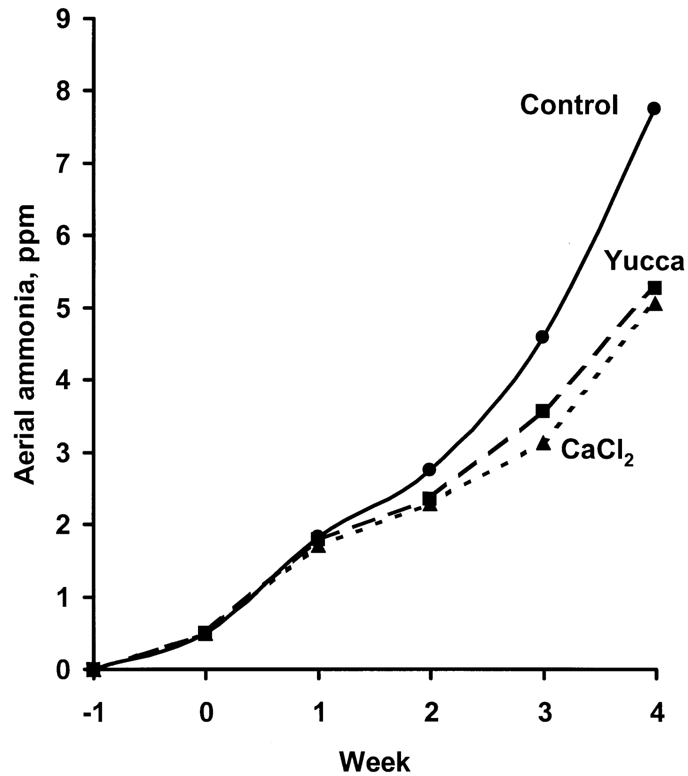

Figure 2. Aerial ammonia concentrations measured by ammonia aspiration tubes in rooms with pigs fed control, *Yucca schidigera* extract, or calcium chloride diets in the major study (Trials 3, 4, and 5); diet × week interaction, wk 3 ($P < 0.07$), and wk 4 ($P < 0.001$). SEM (pooled by week) = 0.27. Weeks –1 to 0 represent the period when a common diet was fed; wk 0 to 4 represent the period when the three experimental diets were fed.

recommended by MidWest Plan Service (MWPS, 1997) for nursery pigs. Nevertheless, results from the daily measurements indicated that ammonia tended to be higher in the rooms with pigs fed the control diet than in rooms with pigs fed the yucca extract diet in both

Table 6. Effect of diet on aerial ammonia concentrations measured by ammonia diffusion tubes and manure characteristics during the major study (Trials 3,[a] 4,[b] and 5[c])

Item	Control	*Yucca schidigera*	Calcium chloride	SEM[d]	*P*-value[e]
Aerial NH_3, ppm (diffusion tubes)[f]	8.9	8.3	5.8	1.22	0.35
Manure N, mg/mL	1.04	1.08	1.11	0.089	0.50
Manure NH_3, ppm	699	674	743	35.1	0.50
Manure pH	6.7	6.7	6.7	0.04	0.78

[a]Five pens with ten pigs (seven barrows and three gilts) per pen. Average initial and final BW were 3.50 and 15.27 kg, respectively; 35-d experiment; 28-d experimental diets.
[b]Five pens with ten pigs (six barrows and four gilts) per pen. Average initial and final BW were 5.90 and 18.85 kg, respectively; 35-d experiment; 28-d experimental diets.
[c]Five pens with ten pigs (five barrows and five gilts) per pen. Average initial and final BW were 4.80 and 17.44 kg, respectively; 35-d experiment; 28-d experimental diets.
[d]Standard error of the mean (n = 3).
[e]Significance of the main effect of diet.
[f]Aerial ammonia concentration measured with diffusion tubes (8-h time period). Measurements were made three times during the last week of the experiment.

the preliminary and major studies. These effects were most evident during the 3rd and 4th wk of the major study, when feed intake and BW were the greatest. The effects of yucca extract may be associated with the glyco-components that it contains. These components bind ammonia and other noxious gases in the slurry, decreasing emissions from the manure pit. Another factor that has been attributed to the reduction of aerial ammonia by adding yucca extract to diets is the inhibition of urease activity (Preston et al., 1987; Duffy and Brooks, 1998). Our results show that yucca extract can be effective in reducing ammonia concentrations in nursery pig facilities. Results of Sutton et al. (1992), Amon et al. (1995), Morel (1997), Cole et al. (1998), and Cromwell et al. (1999) in growing pigs led these authors to a similar conclusion.

The calcium chloride diet also resulted in decreased ammonia concentrations in our studies. Canh et al. (1998) indicated that the addition of calcium salts (1.1 to 2.2% $CaCl_2{\cdot}2H_2O$) to swine diets is an effective method of reducing ammonia emission. In our studies, the lower weight gain of pigs fed the calcium chloride diet was probably at least partly responsible for the decreased ammonia concentrations in these rooms.

Ammonia concentrations measured with diffusion tubes (final week only) were similar to concentrations measured with aspiration tubes during the final week, but the differences among treatments were not significant. Although not analyzed statistically, diffusion tubes indicated considerable within-room variation in aerial ammonia concentration. Lower concentrations of ammonia were measured when tubes were placed on the right side of the rooms (where there was little accumulation of feces) compared with the left side (where feces accumulated) or when placed over the manure pit.

In other research, yucca extract has reduced blood and plasma urea concentrations in rats (Preston et al., 1987; Duffy and Brooks, 1998), poultry (Balog et al., 1994), and steers (Hussain and Cheeke, 1995). However, as in the present study, Duffy and Brooks (1998) did not observe this effect in pigs. In our preliminary study, plasma urea concentrations tended to be lower in pigs fed the calcium chloride diet than in pigs fed the other two diets. The reduced concentrations of plasma urea were probably associated with the reduction in feed intake, although the same effect was not observed in the major study.

Other studies have shown that yucca extract has effects on N metabolism. Morel (1997) found high concentrations of ammonia in manure from pigs fed yucca extract, and Duffy and Brooks (1998) reported that yucca extract probably has an effect on ammonia production in the large intestine, which contributes to the lower levels of ammonia in feces (Ishizaki, 1993). However, in the present study these effects were not observed, and the differences in aerial ammonia concentration cannot be attributed to differences in manure N and ammonia contents.

In accordance with the results of the present study, Canh et al. (1998) did not find any effect of adding calcium salts on the content of N and ammonia in the feces. In our studies, the dietary addition of calcium chloride did not reduce the pH of manure. This result differs from that of Canh et al. (1998). In their study, feces and urine were collected separately in metabolism cages and mixed as slurry. Diets supplemented with the calcium salt resulted in a lower manure pH. Reduced ammonia emission is associated with lower manure pH. In our studies, any feed that was spilled contributed to the manure slurry, and feces and urine became diluted with any drinking water that was wasted by the pigs. Nipple drinkers like the ones we used can result in considerable water usage (Brumm et al., 2000). Thus, the manure was probably more dilute than the manure collected by Canh et al. (1998). Therefore, the reduction that we recorded in aerial ammonia in rooms with pigs fed the calcium chloride diet was probably not related to a decrease in the manure pH, but may have been because the slurry contained more drinking water and was more dilute (Voermans et al., 1996).

Implications

Aerial ammonia concentrations in nursery pig facilities can be reduced by using feed additives such as *Yucca schidigera* extract and calcium chloride. However, the amount of anhydrous calcium chloride added in this research (1.95%) also reduced growth performance. Further research is needed to determine the optimum level of this calcium salt to add to nursery diets so that ammonia concentration can be reduced without reducing growth performance. Lowering ammonia concentrations in pig buildings has important health implications for both pigs and humans working in the buildings.

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