

Effects of dietary ingredients on manure characteristics and odorous emissions from swine¹

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ABSTRACT: Two feeding studies were conducted to examine the impact of dietary inclusion of specific feed ingredients on manure characteristics and manure odor. In one study, 72 finishing pigs were used to evaluate the effects of distillers dried grains with solubles (DDGS) on pig performance, manure characteristics, and odorous emissions. Three diets containing 0, 5, and 10% DDGS were fed during six 4-wk feeding periods. Week 1 served as a dietary adjustment period. Animals were housed in two feeding rooms (six pigs/room) with one treatment/room. A new group of animals (average initial BW = 85.8 kg) was used for each feeding period. Diets were replicated four times. Rooms were equipped with individual shallow manure storage pits that were cleaned once weekly (d 7). On d 4 and 7 of each week, manure pit samples, for chemical analyses, and air samples, for olfactometry analysis, were collected from each room. Odor dilution threshold was greater on d 7

than on d 4 of manure storage across all treatments ($P < 0.01$). No treatment differences in manure composition were noted. In the second study, weaned pigs (approximately 5 wk old) were fed isonitrogenous diets containing 0, 1.5, or 3% bloodmeal. Pigs were housed by diet (three pigs/diet) in one of four individual feeding rooms. A new group of pigs was used for each of the two, 4-wk feeding periods. During period 1, the 3% bloodmeal diet was fed in two of the four rooms; the 0% bloodmeal diet was fed in two rooms during period 2. Manure samples, for chemical analyses, and air samples, for olfactometry analysis, were collected 2 d per week (d 4 and d 6) from each room during wk 2 through 4. No significant treatment differences were observed for odor dilution threshold ($P = 0.30$). Longer manure storage time, 6 d vs 4 d, resulted in a larger odor dilution ratio ($P < 0.01$). Manure composition was unaltered by storage time. Results suggest that odor intensifies during storage.

Key Words: Odors, Manures, Diet, Pigs

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Introduction

Manure odor is produced by the anaerobic breakdown of undigested feed components (Burnett, 1969; Miner, 1977; Ritter, 1989). Alteration of the manure composition, as excreted, may contribute to changes in the odor of decomposing manure. Abatement may occur, to some extent, by diet modification, that is, through the inclusion of highly digestible feeds combined with diets formulated to nearly meet animal needs, resulting in less

substrate available for bacterial breakdown, and thus less odor production (Sutton et al., 1997; Mackie et al., 1998).

Hobbs et al. (1996) observed decreased manure concentrations of odorous compounds with decreasing dietary CP in pigs fed diets containing minimally feasible CP concentrations and supplemental synthetic amino acids. Others have reported increased swine manure odor with increasing dietary sulfur content (Shurson, 1999). Hawe et al. (1992) observed that the addition of dietary fiber significantly increased the excretion of indole and 3-methylindole in the feces of swine, compounds identified as primary contributors to malodor (Spoelestra, 1980; Schaefer, 1977). Sutton et al. (1997) also reported an increase in manure volatile fatty acid content when swine were fed diets containing 5% cellulose. It is plausible that ingredient selection may serve as a means of promoting or preventing the formation of specific manure odorants.

Objectives of this work were 1) to determine whether manure odors differ when pigs are fed different levels

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of by-product ingredients, 2) to determine the chemical composition of manures excreted from pigs fed diets with and without dietary by-products, and 3) to evaluate manure storage time effects on manure odor and composition. Ingredients for the two studies were selected because of their frequent inclusion in swine diets. Both bloodmeal and distillers grains are important sources of nutrients to the swine industry. Yet, their composition may predispose these ingredients to serve as precursors to odor.

Materials and Methods

Distillers Dried Grains Plus Solubles Study

The experiment, conducted at the Iowa State University Swine Nutrition and Management Research Center, was divided into six 24-d periods, beginning March 15, 1999, and ending August 26, 1999. All procedures were conducted in accordance to approved Committee on Animal Care and Usage procedures. A total of 72 crossbred finishing pigs (average initial BW = 85.8 kg) were used over the duration of the trial, 12 pigs fed during each of the six periods. Two environmentally controlled, mechanically ventilated feeding rooms, 3.81 × 3.96 m, were available for the experiment. Within each room, six finishing pigs were housed in a 2.44 × 2.44-m pen with woven-wire flooring. Average room temperature during the course of the experiment was 22.7°C. Two 0.36-m exhaust fans provided the ventilation for each room. Each feeding room was equipped with a shallow manure storage pit under the pen. The pits were emptied using a pull-plug drain. Due to the limited availability of manure storage in each room, the pits were drained and rinsed every 7 d.

Diets were formulated to minimize performance differences in order to focus on manure composition and odor differences that may result. Isolysin diets were formulated using Iowa State University Extension MCS-5 software (Spike et al., 1998). Diets were formulated to contain equal ME:lysine ratios. The control diet was a basal corn-soybean ration and contained no distillers dried grains plus solubles (DDGS). The two dietary treatments included either 5 or 10% DDGS. Previous research in swine has shown that the maximum level of feeding DDGS with no detrimental effect on performance approaches 20%, although mixed results have been reported (Wahlstrom et al., 1970; Harmon, 1974; Harmon, 1975; Cromwell and Stahly, 1986). Therefore, 10% DDGS was selected as the greatest concentration to be fed. The DDGS replaced both corn and soybean meal in an attempt to more closely meet the nutrient requirements of the animal because DDGS contains energy, protein, and essential amino acids at concentrations between those found in corn and soybean meal (Table 1). Three diets were fed in each room on a rotating basis. Due to the fact that only two feeding rooms were available, not all diets were fed concurrently. However, diet assignments were made such that

over the six feeding periods each diet combination was fed in each of the two rooms. Pigs were allowed ad libitum access to feed and water. Feed disappearance was recorded daily. Animals were individually weighed at the beginning and end of each feeding period. Animals were assigned to treatment groups based on weight and sex, allocating matched animals between rooms within a feeding period. A feed sample was collected for laboratory analysis from each batch of feed that was mixed. A total of 19 samples were sent to a commercial lab for individual analysis. Nutrient analyses were conducted on an as-fed basis (average diet dry matter content = 89.11%). Feed samples were analyzed for amino acid content by CN Laboratories (Courtland, MN) using HPLC procedures. Analyses for CP, fiber, gross energy, and sulfur content were conducted by the Dairy One Forage Testing Laboratory (Ithaca, NY) by proximate analyses techniques.

Air samples were collected during the last 3 wk of each 4-wk period, thus allowing the 1st wk for dietary acclimation. Samples were collected on d 4 and 7 each week, prior to pit cleaning (d 4 and 7), and were transported to the Iowa State University campus for analysis. A battery-powered Supelco 10-L Air Sampler (Model 1062, Supelco, Bellefonte, PA) was used to collect air samples in Tedlar bags. During sample collection, the air sampler was placed on the floor as close to the pit as possible.

Room air samples were analyzed using the Ac'scent International Olfactometer (St. Croix Sensory, Stillwater, MN) located in the Olfactometry and Air Quality Laboratory on the Iowa State University campus. The method of dynamic dilution triangular forced-choice olfactometry with an ascending concentration series was used to determine odor concentration (ASTM, 1991). An odor panel consists of a minimum of eight trained human panelists. The panelists underwent training to eliminate any individuals who may have been hyposensitive. During a sample evaluation, panelists were exposed to three different stimuli presented at a sniffing port. Panelists were randomly presented with two blanks (clean, odorless air) and one odorous sample. Serial dilutions were made in which the odorous air is diluted with clean air. The dilutions were twofold. As a panel member progressed through the dilution levels, the proportion of clean dilution air to total airflow decreased, and the proportion of sample air increased. Thus, the dilution decreased and the concentration of odorous air increased with each level. Panelists identified which presentation smelled different from the other two. Panelists had to distinguish one stimulus as being different (guessing if they are unable to detect a difference). Panelists indicated if their responses were a guess or a detection. The detection threshold was the level of dilution at which a panelist was able to correctly detect a difference between the odorous sample and the two blanks. In order to begin below the anticipated detection threshold all presentations were initially presented at the lowest concentration of the odor instru-

Table 1. Composition of experimental diets, kg ingredient per 100 kg complete diet (%)^a

Feedstuff	0% DDGS ¹	5% DDGS	10% DDGS
Corn	86.44	82.20	77.80
Soybean meal	11.26	10.50	9.90
DDGS	0.00	5.00	10.00
Limestone	1.00	1.00	1.00
Dicalcium phosphate	0.70	0.70	0.70
Salt	0.35	0.35	0.35
Vitamin and trace mineral premix ^c	0.25	0.25	0.25

^aDiets fed to six finishing pigs (average initial body weight = 86 kg) per room during each 24-d period.

^bDDGS = distillers dried grains with solubles, expressed as kg DDGS per kg diet.

^cSupplied per kg of diet: vitamin A, 4,409 IU; vitamin D, 1,102 IU; riboflavin, 6.6 mg; pantothenic acid, 17.6 mg; niacin, 33 mg; vitamin B₁₂, 22 µg; Zn, 75 mg; Fe, 87.5 mg; Mn, 30 mg; Cu, 8.75 mg; and I, 0.1 mg.

mentally achievable. The amount of dilution air was decreased until a panelist reached his or her threshold of detection. A panelist completed an evaluation when he or she correctly identified the presentation that contained the odorous sample at one level and then correctly identified the sample at the next level. The panelist had to continue to correctly identify the odorous samples at the next level in order to eliminate the possibility that the sample was identified by chance.

A composite manure sample was collected from the pit in each room, following manual mixing and agitation. All manure analyses were conducted in the Iowa State University Department of Animal Science. To determine the amount of total solids (**TS** or dry matter, **DM**), manure samples were oven-dried in porcelain crucibles for 3 to 4 d at 55°C until a consistent dry weight was obtained (APHA, 1998, Method 2540B). Dried samples were ashed in a muffle furnace at 550°C for 5 h to determine volatile solids content (**VS** or organic matter, **OM**) (APHA, 1998, Method 2540E). Sample chemical oxygen demand (**COD**) was determined using Hach digester tubes according to Hach method 8000 (Hach, Loveland, CO). The colorimetric reaction was measured using a spectrophotometer, wavelength 620 nm. Total phosphorus content was analyzed using procedures of AOAC, 1990, Method 7.123) involving an acid digestion procedure followed by colorimetric determination using molybdovanadate for color development. Total Kjeldahl nitrogen was determined using acid digestion with a selenium catalyst followed by distillation (AOAC, 1990, Method 2.057).

Data were analyzed using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Room served as the experimental unit in the incomplete randomized block design. Dietary influence on odor concentration was evaluated using a model that included the fixed effects of diet, week of collection, day of collection, panelist, and interactions of diet and week and day of collection. Feeding period and a day, week of collection interaction term were included as random variables. Because only two rooms were available for the experiment, but three dietary treatments were considered, diet was confounded within the room × period interaction. To test

the main effects of diet, the denominator term used had 4 degrees of freedom. Denominator for tests involving week and day of collection terms was the random interaction term including these effects (df = 49). Single degree of freedom linear contrasts were used to test the effects of diets (5 % vs 10% DDGS and control vs mean of 5 and 10% diets). Least squares means of day of collection were compared within diets using multiple means comparisons.

Data for manure composition were available for all samples collected and included a total of 72 samples. A model similar to the one used for odor concentration was used, except the model for manure concentration did not include terms for panelist or for the random day, week interaction term. To test the main effects of diet, the denominator term used had 4 degrees of freedom. Residual was the error term used to test other effects. Single degree of freedom linear contrasts were used to test effects of diets (5 % vs 10% DDGS and control vs mean of 5 and 10 % diets) and collection days (d 4 vs d 7).

To relate human panelist response to manure characteristics, Pearson correlation procedures were used. Original values for odor dilution were measured on an exponential scale, thus for statistical analyses it was necessary to normalize these data using a natural log transformation. Originally, analyses were completed for odor dilution and the transformed natural log of dilution; transformation of this variable did not influence conclusions. Thus, discussion generally will include only results for the transformed variable. Differences in nutrient composition of the three diets were compared using a model that included diet and date that diet was sampled as fixed effects to determine whether composition might contribute to differences in manure and odor characteristics.

Bloodmeal Study

The second experiment, conducted at the Iowa State University Laboratory Animal Resource facilities within the College of Veterinary Medicine, was divided into two 4-wk feeding periods. All procedures were con-

Table 2. Dietary treatment formulation composition of dietary treatments containing 0%, 1.5%, or 3% dietary bloodmeal (BM)

Ingredient	0% BM	1.5% BM	3% BM
	kg ingredient per 1,000 kg feed fed		
Yellow corn	657.40	680.00	705.20
Spray-dried bloodmeal	0.00	15.00	30.00
Dehulled soybean meal	310.00	272.20	232.00
Synthetic lysine	0.10	0.10	0.10
Dical phosphate	15.00	15.20	15.20
Limestone	8.80	8.80	8.80
Salt	4.20	4.20	4.20
Minerals	4.50	4.50	4.50
Lysine, %	1.12	1.12	1.12
Threonine, %	0.77	0.76	0.75
Tryptophan, %	0.25	0.24	0.23
Met + Cys, %	0.67	0.66	0.64
ME, kcal/kg	3,271	3,260	3,252

ducted in accordance to approved Committee on Animal Care and Usage procedures. A total of 24 weaned pigs, approximately 5 wk of age were used over the course of the feeding trial; 12 pigs during each feeding period. Pigs were divided into groups of three and each group housed in one of four mechanically ventilated feeding rooms. Within each room, pig groups were maintained in 1.2- × 1.2-m raised pens over manure collection pits (30 cm deep). Drinking water was provided using nipple waterers bracketed to the side of each pen. Room temperature was maintained at 25°C. Manure collection pits were emptied once weekly (d 7).

Three isonitrogenous treatment diets were formulated using Iowa State University Extension MCS-5 software (Spike et al., 1998) to contain 0, 1.5, or 3% bloodmeal (Table 2). Diets were formulated to minimize performance differences in order to focus on manure composition and odor differences that may result. During both periods, all pigs in a room received the same diet and all diets were fed during each period. Additionally, during period 1, the 3% bloodmeal diet was fed in two of the four rooms; the 0% bloodmeal diet was fed in two rooms during period 2. Pigs were allowed ad libitum access to feed and water. Feed disappearance was recorded weekly. Animals were individually weighed at the beginning and end of each feeding period. Animals were assigned to treatment groups based on weight and sex, providing a similar animal profile between rooms within a feeding period.

Air samples (10-L tedlar bags) were collected twice weekly (d 4 and d 6) from each feeding room during wk 2 through 4 of each feeding period. Air samples were analyzed for odor dilution threshold using olfactometry procedures described previously. Aerial hydrogen sulfide concentration of each room was determined using Sensidyne short-term exposure tubes (Sensidyne, Clearwater, FL) and the same sampling schedule as used for olfactometry air sample collection.

Following manual mixing and agitation, a composite manure sample was collected from the pit in each room.

Table 3. Least squares means of nutrient composition of experimental diets for finishing pigs containing 0, 5, or 10% DDGS^a

Nutrient ^b	0% DDGS	5% DDGS	10% DDGS
CP, %	12.09 ^x	12.51 ^x	13.34 ^y
ADF, %	4.29 ^x	4.50 ^x	5.38 ^y
NDF, %	8.16 ^x	9.56 ^y	10.66 ^z
NEG, mcal/lb	0.58 ^x	0.57 ^y	0.57 ^z
Amino acids			
Lys, %	0.65	0.63	0.64
Trp, %	0.12	0.11	0.12
Thr, %	0.45 ^x	0.46 ^{xy}	0.48 ^y
Val, %	0.58 ^x	0.59 ^x	0.63 ^y
Leu, %	1.18 ^x	1.24 ^y	1.34 ^z
Ile, %	0.48 ^x	0.49 ^{xy}	0.52 ^y
Phe, %	0.60 ^x	0.61 ^x	0.65 ^y
Tyr, %	0.49 ^x	0.50 ^x	0.54 ^y
Met, %	0.24 ^x	0.24 ^x	0.26 ^y
Cys, %	0.25 ^x	0.26 ^x	0.27 ^y
Minerals			
Ca, %	0.64	0.65	0.63
P, %	0.44 ^x	0.46 ^y	0.48 ^y
S, %	0.12 ^x	0.13 ^y	0.15 ^z

^aDDGS = distillers dried grains with solubles, expressed as kg DDGS per kg diet.

^bCP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, NEG = net energy for gain, all analyzed on as-fed basis.

^{x,y,z}Means within a row with different superscripts differ ($P < 0.10$).

Samples were collected twice weekly (d 4 and 6) from each feeding room during wk 2 through 4 of each feeding period. Manure samples were analyzed at Iowa State University for DM, OM, total Kjeldahl N (TKN), P, and COD using the methods described previously. Potassium content of manure was analyzed using AOAC (1990) Method 949.01.

Data were analyzed using mixed model procedures of SAS (1997). Olfactometry results were transformed to normalize their distribution by using a natural logarithm function. Models used to evaluate manure composition and olfactory results were similar to those used for the DDGS study. However, for the current study, individual panelist results were not available, and thus models for olfactory data did not include terms for panelist or the week × day of collection interaction. Error degrees of freedom for testing the main effect of diet was 4. Single degree of freedom linear contrasts were used to test the effects of diet (1.5% vs 3% BM and control vs mean of 1.5% and 3% diets). For olfactory data, least squares means of day of collection were compared within diets using multiple means comparisons. Pearson correlations were used to relate olfactometer results with chemical data.

Results

Distillers Dried Grains Plus Solubles Study

Dietary treatment compositions, pooled over time, are presented in Table 3. Dietary inclusion of DDGS

Table 4. Least squares means of animal performance measures over 24-d periods, as influenced by dietary inclusion of 0, 5, or 10% DDGS^a

Item	0% DDGS	5% DDGS	10% DDGS
Initial BW, kg	84.4	85.9	87.0
Final BW, kg	103.0	105.3	105.9
ADG, kg	0.80	0.79	0.78
ADFD, kg ^b	2.75 ^x	2.73 ^x	2.91 ^y
Feed:Grain	0.29	0.30	0.26

^aDDGS = distillers dried grains with solubles, expressed as kg DDGS per kg diet.

^bADFD = average daily feed disappearance per pig, calculated as total feed into room per period divided by six pigs per room and 24 d per period.

^{x,y}Means within a row with different superscripts differ ($P < 0.10$).

did not affect ADG or feed efficiency ($P > 0.05$, Table 4). There was greater feed disappearance ($P < 0.10$) by the pigs fed the 10% DDGS diet. There was no difference in feed disappearance between pigs fed diets containing 5% DDGS and the control diet.

No significant differences due to diet were observed for total solids, volatile solids, chemical oxygen demand, total Kjeldahl nitrogen, or phosphorus content of manure ($P > 0.10$). Day was a significant ($P < 0.05$) model variable for each of these parameters. Determination of Pearson correlations between manure analytes and odor dilution threshold of room air samples indicated that manure P content was the manure variable most highly correlated ($r = -0.28$, Table 6) to odor, followed by TKN to a lesser extent ($r = -0.21$, Table 6). Given that P is nonvolatile and not often regarded as a mineral that would contribute to odor nuisance, it is unclear at this time why P was the most highly correlated variable. Manure TKN content is a more logical determinant of malodor potential. The negative correlation likely reflects volatilization of manure N into the room air where samples were collected for odor analysis. As more N volatilized, manure TKN content decreased yet N content of the room air increased. The N-containing compounds in the room air are likely contributors to malodor.

Table 5. Least squares means of compositional measures for manure collected on d 4 and d 7 of each week from pigs fed differing levels of DDGS^a

Measure	Day		Significance for contrast ^b
	4	7	
Total solids, %	19.8	15.8	**
Volatile solids, %	16.7	13.2	**
Chemical oxygen demand, g/L	8.73	7.41	*
Total Kjeldahl nitrogen, g/g DM	2.82	2.77	NS ^c
Phosphorus, g/g DM	2.04	1.89	NS

^aDDGS = distillers dried grains with solubles, expressed as kg DDGS per kg diet.

^bSignificance level for linear contrast of d 4 – d 7.

^cNS indicates contrast was not significant.

* $P < 0.05$.

** $P < 0.01$.

There were no significant treatment effects on odor dilution threshold. However, a nonsignificant ($P = 0.16$) linear trend for increasing odor concentration with increasing dietary content of DDGS was noted. Odor dilution was affected by day ($P < 0.01$, Table 7) and panelist ($P < 0.01$). Number of days that manure had been stored resulted in an increase in log odor dilution, irrespective of diet fed, likely due to some anaerobic decomposition of the manure with the consequential production of odorous intermediate degradation products. A panelist effect on odor dilution threshold was expected because of the inherent variability among human beings. Sensory perception of an odor is an individual response, differing from one person to the next. The proportion of total variability in the odor concentration measurements explained by differences between the panelists over the treatments indicated that only a quarter of the total variability in the olfactometry analysis was accounted for by differences between the panelists ($r = 0.23$, intraclass correlation). The olfactometry training process during which individuals are screened to ensure they are neither hypo- nor hypersensitive to odors is designed to minimize the differences among the panelists. The low variability among the panelists within the treatments across time ($r = 0.12$, interclass correlation) suggests that individual panelist responses were consistent over time.

Bloodmeal Study

Average daily gain among treatment groups was similar, 0.6 kg/d. No significant odor intensity differences were observed between manures from pigs fed the three treatment diets ($P = 0.30$). Due to a very large daily variation in panelist response, two panelist responses were omitted. These panelists reported intensities of manure odor from pigs fed the control diet during period 1 that were more than 3 SD from the mean response for other treatments during the first period. Length of time manure had been stored in each room, 4 or 6 d, was important for manure odor intensity. Longer storage time resulted in the largest odor dilution ratio ($P < 0.01$, Table 8), likely for the reasons that this effect was observed in the DDGS study.

Manure composition and room hydrogen sulfide concentration were unaltered by storage time and not significantly affected by diet (Table 9). Likewise, storage time did not affect odor differently for the three treatments (treatment \times time). Worth noting, however, is that when compared to the industry-accepted table values of manure production and characteristics (ASAE, 2000) most often used by engineers for manure storage design purposes, pigs used in this study excreted considerably lower concentrations of N, P, and K than values reported for similar nursery pigs in that table. Table values were determined based on few animals in the 1970s so likely do not accurately reflect today's animal. Determination of Pearson correlations between manure analytes and log odor dilution threshold of room air

Table 6. Pearson correlations of odor and manure characteristics from pigs fed differing levels of distillers dried grains with solubles

Measure	(2)	(3)	(4)	(5)	(6)	(7)
(1) Odor dilution	0.95**	-0.19	-0.16	-0.16	-0.15	-0.28*
(2) Odor dilution natural log	1.0	-0.18	-0.15	-0.188	-0.21†	-0.21†
(3) Total solids, %		1.0	0.99**	0.45**	0.24*	-0.19
(4) Volatile solids, %			1.0	0.43**	0.23*	-0.28*
(5) Chemical oxygen demand, g/L				1.0	0.21†	0.11
(6) Total Kjeldahl nitrogen, g/g					1.0	-0.02
(7) Phosphorus, g/g						1.0

† $P < 0.10$.* $P < 0.05$.** $P < 0.01$.

samples indicated that manure P content was the manure variable most highly correlated ($r = 0.42$, Table 10) to odor, followed by K ($r = 0.35$) and, to a lesser extent, TKN ($r = -0.25$, Table 10). These results are similar to those observed in the DDGS study, in which K was not measured. However, in this study P was positively correlated with odor measures. Again, we have no obvious explanation for the degree of correlation between nonvolatile minerals and odor. It is interesting to note that the correlation coefficient for TKN was similar in both studies and, in both cases, negative.

Discussion

Changes in feed ingredients potentially affect manure odor through one or more of several mechanisms, some of which include more efficient use of nutrients supplied, more nearly meeting animal needs without providing excess nutrients, changes in fermentation patterns within the animal, and postexcretion decomposition patterns. In both feeding studies, diets were formulated to minimize performance differences in order to focus on manure composition and odor differences that may result. In the first study, DDGS was selected to replace corn and soybean meal because it is a potentially abundant by-product of the ethanol industry. However, as a result of processing, the sulfur content of DDGS is greater than that of either corn or soybean

meal. Excretion of excess dietary sulfur can lead to the production of sulfur-containing compounds that can contribute to malodor. Bloodmeal was selected to replace soybean meal because it is a common feed ingredient for nursery pig diets due to its high crude protein and amino acid content. Although it is a good source of lysine and methionine, diets containing bloodmeal may provide excesses of other amino acids, which, upon excretion, can form odorous metabolites. In the DDGS study, protein, sulfur amino acids (methionine and cysteine), and elemental sulfur content increased slightly with increasing content of DDGS. Any amino acid excesses in diets fed in either study would have been broken down anaerobically to volatile fatty acids, phenols, and indoles, which would have contributed to the odor perceived by the human panelists during olfactometry. Changes in hindgut microflora due to diet differences might also have occurred to a small extent.

Compositional differences of the manure characteristics were not influenced by diet in either study. Total nitrogen content did not differ between manures in either study; however, compositional analyses of N-containing compounds that appear to be most associated with odor were not conducted (Schaefer, 1977; Spoelstra, 1980). Similarly, VFA content of the manure, which may result from either protein or starch digestion, was not measured in the manure. Likely, any odor effects that would be observed would be due to differences

Table 7. Least squares means of odor panel results obtained when pigs were fed diets containing different levels of distillers dry grains with solubles

Diet	Odor dilution		Log odor dilution		Significance for difference ^b
	Day 4 ^a	Day 7 ^a	Day 4	Day 7	
	Least Squares Mean				
0% DDGS ^c	163.7	441.6	4.89	5.72	**
5 % DDGS	212.9	436.5	5.05	5.62	**
10% DDGS	238.3	475.8	5.06	5.77	**

^aDay = day of sampling each week, either d 4 or d 7.^bSignificance level for differences between d 4 and 7 of log dilution.^cDDGS = distillers dried grains with solubles, expressed as kg DDGS per kg diet.** $P < 0.01$.

Table 8. Least squares means for measures of composition of manure from finishing pigs fed diets containing different levels of bloodmeal

Compositional measure	Diet			Largest SEM ^a
	0% Bloodmeal	1.5% Bloodmeal	3% Bloodmeal	
Room air hydrogen sulfide, ppm	1.49	1.25	0.97	1.09
Total Kjeldahl nitrogen, mg/g	36.0	37.9	35.3	4.40
Phosphorus, mg/g	31.5	31.0	34.7	7.80
Chemical oxygen demand, mg/g	1,359.4	1,165.8	1,132.4	104.4
Potassium, mg/g	8.20	8.97	7.60	5.12
Total solids, %	0.298	0.311	0.317	0.0120
Volatile solids, %	0.256	0.272	0.275	0.0097

^aLargest standard error of means for diets.

within the protein and(or) starch components of the manure. Gas chromatographic analysis of collected air samples, including quantification of protein and starch digestion products, were measured in the DDGS study and are reported elsewhere (Gralapp et al., 2001). Diet did affect concentration of measured aerial analytes, helping to explain the increased odor dilution threshold with increasing dietary concentration in the DDGS study. However, although manure compositional differences may have produced air samples in which chemical differences were detected, the diet effects were not great enough to result in observed differences by the panelists.

Manure storages were rinsed and drained on a weekly basis. The first sampling day of each week reflected 4 d worth of manure storage and accumulation, whereas the second sampling day represented 7 d in the DDGS study and 6 d in the bloodmeal study. In both studies, as the storage time of the manure increased, the anaerobic breakdown of the manure would have progressed. Because the amount of manure in the storage pit increased from one sampling day to the next, within a week, the odor generated from the manure would be expected to increase. As more manure was added to the pit each day, more substrate was available for breakdown by bacteria, and thus greater concentrations of odorous compounds could have been generated. Also, the dissolved oxygen available may have decreased, and the resultant shift to anaerobic breakdown

may have generated compounds of a more odorous nature, such as branched-chain fatty acids. Manure compositional differences were observed in the DDGS study only, perhaps due to the extra day of storage and the greater quantity of manure that was present from the finishing pigs compared to the nursery pigs. The larger manure storage surface area per unit pig weight in the bloodmeal study may have prevented sufficient mixing of urine, feces, and drinking water to provide anaerobic decomposition. However, in both studies the solids would have been expected to decompose to some extent with manure storage, and the dilution would have increased as wasted water from the drinkers and the sprinklers entered the pit. Although no differences were observed with storage time, N would have been expected to be lost through ammonia volatilization. The COD decreased with increasing storage time and extent of decomposition ($P < 0.05$), with decreases ranging from 22 to 33% in the DDGS study. Previous work has demonstrated positive correlations between manure biological oxygen demand content and odor (Williams, 1984), although in our DDGS study we suspect that COD reduction corresponded to the formation of odorous intermediates in the decomposition process. The bloodmeal study supported findings by Williams (1984) that COD was an important factor in determining panelist odor assessment. Sampling error in collecting manure from the pits may have contributed to the differences observed, particularly with respect to day effects on phosphorus content (measured on a dry basis) in the DDGS study. Volatility and degradation of other constituents may have played a role in the determination of P and K as the measures most highly correlated to odor in that P and K concentrations were less variable over time.

Table 9. Least squares means of odor panel results obtained when pigs were fed diets containing different levels of bloodmeal

Diet	Odor dilution		Log odor dilution		Significance for difference ^b
	Day 4 ^a	Day 6 ^a	Day 4	Day 6	
0% Bloodmeal	41.0	177.6	3.51	5.12	**
1.5% Bloodmeal	120.9	313.2	4.31	5.56	**
3% Bloodmeal	78.4	278.8	4.06	5.08	**

^aDay = day of sampling each week, either d 4 or d 6.

^bSignificance level for differences between d 4 and 6 of log dilution.
** $P < 0.01$.

Implications

By-product feeds are important components of livestock rations for both economic and nutritional reasons. In many cases, if by-products were not used as feed sources, they would be added to landfills. However, the nutrient content and digestibility of by-products may contribute to greater manure odor than traditional corn-soy diets. Although significant alteration in odor

Table 10. Pearson correlations of odor and manure characteristics when nursery pigs were fed diets containing bloodmeal

Measure	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Odor dilution	0.86**	0.12	0.15	0.09	-0.10	0.35*	-0.14	0.30*
(2) Odor dilution natural log	1.0	0.19	0.22	0.05	-0.25†	0.42**	-0.07	0.35*
(3) Total solids, %		1.0	0.98**	-0.18	-0.04	0.08	-0.003	-0.15
(4) Volatile solids, %			1.0	-0.16	-0.03	0.10	-0.04	-0.08
(5) Chemical oxygen demand, mg/g				1.0	0.47**	-0.41**	-0.09	-0.36*
(6) Total Kjeldahl nitrogen, mg/g					1.0	-0.62**	-0.04	-0.50**
(7) Phosphorus, mg/g						1.0	-0.14	0.84**
(8) Room air hydrogen sulfide, ppm							1.0	-0.06
(9) Potassium, mg/g								1.0

† $P < 0.10$.* $P < 0.05$.** $P < 0.01$.

concentration was not observed with the dietary inclusion of these particular by-products, the impact of long-term storage on manure decomposition and associated odor was not considered. Under short-term manure storage, increased odor was observed due to time of storage and manure accumulation.

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