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# Growth performance, carcass characteristics, nutrient digestibility and fecal odorous compounds in growing-finishing pigs fed diets containing hydrolyzed feather meal<sup>1</sup>

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**ABSTRACT:** This study was designed to determine the effects of hydrolyzed feather meal inclusion on growth performance, carcass characteristics, nutrient digestibility and fecal odorous compounds in modern lean growth genotype pigs. Two hundred forty pigs (BW = 23.2 ± 1.3 kg) were allotted based on BW and sex to a 2 × 6 factorial arrangement of treatments (four pens per treatment; five pigs per pen) in a randomized complete block design. Factors consisted of 1) sex (barrows or gilts) and 2) dietary treatment (0, 2, 4, 6, 8, or 10% hydrolyzed feather meal). Diets were formulated to contain 1.00, 0.90, 0.75, or 0.60% apparent ileal digestible lysine for phases 1 to 4, respectively, with other amino acids provided at an ideal ratio. Available P and ME were kept constant within each phase. No significant interactions between feather meal inclusion and sex were observed for growth performance ( $P > 0.15$ ). Body weight gain was reduced ( $P < 0.05$ ) for pigs fed 10% feather meal compared to pigs fed 0, 4, or 8% feather meal. Feed intake of pigs fed 10% feather meal was reduced ( $P < 0.05$ ) compared to pigs fed 0 or 4% feather meal. Ultrasound backfat measurements tended ( $P =$

0.12) to increase with increasing levels of feather meal. Daily lean gain was less ( $P < 0.05$ ) in pigs fed 10% feather meal than in pigs fed either 0, 2, 4, or 8% feather meal. Digestibility of N measured on wk 9 decreased quadratically ( $P < 0.001$ ) with increasing levels of feather meal. Phosphorus digestibility increased in a linear fashion ( $P < 0.02$ ), however, the improvement in P digestibility with increasing levels of feather meal was more pronounced in barrows compared to gilts (interaction,  $P < 0.05$ ). Fecal samples obtained from pigs fed 0, 4, or 8% feather meal were analyzed for odorous compounds. Concentrations of butanoic, pentanoic, and 3-methylbutanoic acid were greater ( $P < 0.05$ ) and concentrations of 3-methylphenol, 4-methylphenol, indole, and decane were less ( $P < 0.05$ ) in feces from pigs fed feather meal. These results suggest that feather meal can be included in diets for growing-finishing pigs at a rate of 8%. Excretion of N in feces increased but P excretion decreased with increasing levels of feather meal. Odorous compounds in feces can be affected by the inclusion of hydrolyzed feather meal, but the exact impact of these changes on odor perception remains to be elucidated.

Key Words: Carcasses, Digestibility, Feather Meal, Growth, Pigs

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## Introduction

Feather waste from the poultry processing industry can potentially be used as a protein source in animal

feeding operations. Improvements in current processing methods that hydrolyze proteins in feathers to make them more digestible for nonruminant animals have led to the availability of high-quality hydrolyzed feather meals that could provide a viable economic livestock feed (Papadopoulos, 1985). However, feather meal has not been used extensively in the swine industry because of concerns regarding the quality of feather meal and the possible impact of feather meal on the growth performance of pigs.

Traditionally, it has been recommended to limit the use of feather meal in growing-finishing pig diets to a maximum of 5% (Seerley, 1991). Very few research studies have been conducted to evaluate the potential inclusion rate of feather meal in practical swine diets. Combs et al. (1958) reported that 7.5% steam-hy-

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drolyzed feather meal was acceptable in diets for pigs when supplemented with lysine. Chiba et al. (1995) detected no differences in performance of pigs fed 15% feather meal compared to soybean meal diets. In a subsequent study, Chiba et al. (1996) suggested that 9% feather meal could be used in finishing pigs without affecting pig growth or carcass characteristics, although results were not conclusive.

Inclusion of feather meal on an amino acid basis may increase the protein content of the diet and therefore increase excretion of nitrogen into the environment (Chiba, 2001). Increasing the crude protein content of the diet has also been suggested to increase the production of odorous compounds (Hobbs et al., 1996).

Therefore, the objective of this study was to determine the effects of hydrolyzed feather meal inclusion on growth performance, carcass characteristics, nutrient digestibility, and fecal odorous compounds in modern lean growing-finishing pigs.

## Materials and Methods

### *Animals and Treatments*

The experimental protocols used in this study were approved by the North Carolina State University Institutional Animal Care and Use Committee. A total of 240 pigs (initial BW was  $23.2 \pm 1.3$  kg) were allotted based on BW and sex to a  $2 \times 6$  factorial arrangement of treatments (four pens per treatment; five pigs per pen) in a randomized complete block design. Modern genotype pigs were used in this trial and were considered typical of pigs used by the integrated swine industry in North Carolina. Factors consisted of 1) sex (barrows or gilts) and 2) dietary treatment (0, 2, 4, 6, 8, or 10% of hydrolyzed feather meal inclusion). Pigs were fed four diets (Tables 1 and 2) during the growing-finishing period to closely match their nutrient requirements with their growth rate and feed intake, and to mimic feeding programs typically used in the modern swine industry. The diets were formulated based on apparent ileally digestible amino acids and available P, and they met all nutrient requirements as suggested by NRC (1998). Apparent ileal digestibility estimates from NRC (1998) were used for all ingredients, including feather meal. The feather meal used in this trial was produced by steam-hydrolyzing raw feathers with added blood. This process breaks the keratin bonds between proteins in feathers and makes a highly digestible, high-protein product. After hydrolyzing, the feather meal was ring-dried to below 10% moisture and screened. The hydrolyzed feather meal was analyzed for amino acid composition and was found to contain 2.12% lysine, 0.62% methionine, 3.81% cysteine, 3.88% threonine, 0.56% tryptophan, 6.17% valine, 0.99% histidine, 6.98% leucine, and 3.85% isoleucine.

Pigs were housed in a curtain-sided grower-finisher building on solid floors using 48 pens with five pigs

per pen. Each pen was 1.52 m wide and 3.66 m in length, providing  $1.11 \text{ m}^2$  of space per pig. Two nipple waterers and a self-feeder with two feeding holes were provided in each pen. Pigs were monitored on a daily basis to ensure that they were healthy and that their feeders and waterers were functioning properly. Floors were cleaned daily to avoid manure buildup in the pens. Eight pigs were removed from the trial due to death, sickness, or poor growth. Performance data were adjusted based on BW and days on test. The trial was conducted during the summer months of the year.

### *Measurements*

Pig weights and feed intake were measured every 4 wk, and their diets were switched at wk 4, 8, and 12 of the trial when they averaged 44.7 kg, 70.1 kg, and 94.0 kg BW, respectively. Ultrasound (Aloka 500, Ithaca, NY) measurements to determine backfat, loin eye area, percentage fat-free lean, and lean gain were taken when pigs were weighed to evaluate the effects of feather meal on carcass characteristics. Percentage fat-free lean and lean gain were calculated according to NPPC (1991) equations.

Fecal digestibility of DM, N, and P was measured in wk 9 of the trial (during Phase III) using the marker method. Chromium oxide (Fisher Scientific, Fair Lawn, NJ) was used as an indigestible marker and was mixed with starch at a ratio of 1:3. This mixture was then included in the treatment diets to provide 0.10% chromium oxide. Diets were fed for 1 wk and subsequently fecal grab samples were collected once in the morning and once in the afternoon from at least two pigs per pen. Samples were combined by pen and stored at  $-20^\circ\text{C}$  until they were analyzed. Determination of DM, N, and P was conducted according to AOAC (1997) procedures. Analysis of Cr was conducted by wet-ashing 2 g of sample with 10 mL of nitric acid and 7 mL of perchloric acid (AOAC, 1997). Chromium was determined using an inductively coupled plasma spectrometry instrument (ICP; Fison model 3410, Dearborn, MI).

Odorous compounds were analyzed in fecal samples as described by Rizzuti et al. (1999). Briefly, 1 g of fecal sample was first mixed with 10 mL of deionized water and centrifuged ( $6,000 \times g$ ) for 10 min. Samples were extracted using 75- $\mu\text{m}$  polydimethylsiloxane/carboxen Solid Phase Micro-Extraction (SPME) fibers (Supelco, Bellefonte, PA) with an adsorption time of 20 min. The SPME fibers were desorbed directly into the injection port of a gas chromatography-mass spectrometer (HP 6890Plus, Hewlett Packard Company, Palo Alto, CA). Standard solutions containing odorous compounds (acetic acid, propionic acid, iso-butyric acid, butanoic acid, 3-methylbutanoic acid, pentanoic acid, phenol, 3-methylphenol, 4-methylphenol, 2-ethylphenol, 3-ethylphenol, 4-ethylphenol, 2,6-bis(1,1-dimethylethyl)phenol, indole, 2-methylindole, 3-methylindole, 4-methylindole, decane, undecane,

**Table 1.** Composition of the experimental grower diets (as-fed basis)

Item	Early grower diets <sup>a</sup>						Late grower diets <sup>b</sup>					
	Feather meal inclusion, %						Feather meal inclusion, %					
	0	2	4	6	8	10	0	2	4	6	8	10
<b>Ingredient, %</b>												
Corn	59.81	61.57	63.32	62.40	61.25	60.10	64.99	66.74	67.96	66.82	65.67	64.52
Soybean meal (48% CP)	33.36	29.12	24.87	23.40	22.17	20.94	28.47	24.23	20.53	19.30	18.06	16.83
Limestone	0.79	0.80	0.81	0.81	0.80	0.80	0.77	0.78	0.79	0.79	0.79	0.78
Dicalcium phosphate	1.20	1.22	1.24	1.23	1.23	1.22	1.07	1.09	1.10	1.10	1.09	1.09
Vitamins-minerals <sup>c</sup>	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Antibiotic <sup>d</sup>	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Feather meal <sup>e</sup>	—	2.00	4.00	6.00	8.00	10.00	—	2.00	4.00	6.00	8.00	10.00
Poultry fat	3.94	4.30	4.66	5.03	5.40	5.78	3.80	4.16	4.51	4.89	5.26	5.64
Lysine·HCL	0.05	0.16	0.26	0.29	0.30	0.31	0.07	0.18	0.27	0.28	0.30	0.31
DL-Methionine	0.04	0.03	0.04	0.04	0.05	0.05	0.02	0.02	0.03	0.03	0.03	0.03
<b>Calculated composition</b>												
Crude protein, %	20.88	20.82	20.78	21.69	22.72	23.76	19.00	18.94	19.06	20.09	21.13	22.17
Lysine, % <sup>f</sup>	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90
Methionine, %	0.32	0.30	0.30	0.30	0.30	0.30	0.28	0.27	0.27	0.27	0.27	0.27
Sulfur amino acids, %	0.60	0.61	0.65	0.70	0.75	0.80	0.54	0.56	0.60	0.65	0.70	0.75
Threonine, %	0.60	0.60	0.60	0.63	0.67	0.71	0.54	0.54	0.55	0.58	0.62	0.66
Tryptophan, %	0.20	0.19	0.17	0.17	0.17	0.17	0.18	0.16	0.15	0.15	0.15	0.15

<sup>a</sup>Diets were formulated to contain 3,500 kcal/kg of ME, 0.70% Ca, and 0.30% available P.

<sup>b</sup>Diets were formulated to contain 3,500 kcal/kg of ME, 0.65% Ca, and 0.27% available P.

<sup>c</sup>Supplied per kg of complete diet: 5,540 IU of vitamin A as retinyl acetate, 1,108 IU of vitamin D<sub>3</sub>, 22 IU of vitamin E as dl- $\alpha$ -tocopherol acetate, 1.98 mg of vitamin K as menadione dimethylpyrimidinol bisulfite, 165 mg of choline as choline chloride, 22 mg/kg of niacin, 17.6 mg of d-pantothenic acid as dl-calcium pantothenate, 4.4 mg of riboflavin, 1.1 mg of pyridoxine as pyridoxine·HCl, 0.55 mg thiamine as thiamine mononitrate, 0.022 mg of vitamin B<sub>12</sub>, 0.33 mg of folic acid, 0.04 mg of d-biotin, 110 mg Zn as ZnSO<sub>4</sub>, 110 mg Fe as FeSO<sub>4</sub>, 22 mg Cu as CuSO<sub>4</sub>, 55 mg Mn as MnO, 0.28 mg I as EDDI, and 0.30 mg Se as NaSeO<sub>3</sub>.

<sup>d</sup>Provided 55 mg chlortetracycline/kg of complete feed.

<sup>e</sup>Hydrolyzed feather meal (Pilgrims Pride Eastern Division, Broadway, VA).

<sup>f</sup>Amino acids are expressed on a calculated ileal apparent digestible basis.

dodecane, pentane, gamma-butyrolactone, nonanal, 1-decene, tridecane, tetradecane, nonane, carbon disulfide, dimethyl disulfide, ethanethiol (ethyl mercaptan), propanethiol, and butanethiol) were used to derive standard curves for quantifying the occurrence of these compounds in fecal samples.

### Statistical Analyses

Daily gain, feed intake, feed efficiency (gain/feed), ultrasound carcass composition, and lean gain were calculated for the grower phase (early and late grower phases), the finisher phase (early and late finisher phases), and overall. Data were analyzed as a randomized complete block design using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). An interaction between sex and feather meal was observed for initial weight ( $P < 0.04$ ) and, therefore, initial weight was used as a covariate in the final model for growth performance data. The model further included sex, feather meal inclusion level, and the sex  $\times$  feather meal inclusion interaction. Pig BW at the end of the grower or finisher phase was used as a covariate for ultrasound carcass measurements. Significant differences between the different inclusion levels were determined following a significant  $F$ -test by using the least significant difference method. Linear, quadratic,

and cubic polynomials were used to analyze digestibility data.

## Results and Discussion

No significant interactions between feather meal inclusion and sex were observed for growth performance ( $P = 0.15$ ). Therefore, data were combined and only main effects of feather meal inclusion are presented. Final BW at the end of the experiment (wk 16) was reduced by 5% ( $P < 0.05$ ) for pigs fed diets containing 10% feather meal compared to control pigs (Table 3). Daily gain, feed intake, and feed efficiency were not affected ( $P > 0.14$ ) by feather meal inclusion rate during the grower phase. During the finisher phase, feed intake was reduced ( $P < 0.05$ ) in pigs fed 10% feather meal compared to pigs fed 0, 4, or 8% feather meal. For the overall growing-finishing period, BW gain was reduced ( $P < 0.05$ ) for pigs fed 10% feather meal compared to pigs fed 0, 4, or 8% feather meal. Feed intake of pigs fed 10% feather meal was reduced ( $P < 0.05$ ) compared to pigs fed 0 or 4% feather meal for the overall growing-finishing period. Feed efficiency was not affected by feather meal inclusion. These results indicate that feather meal can be included in diets for growing-finishing pigs at a level of 8% without negatively impacting growth performance. This level

**Table 2.** Composition of the experimental finisher diets (as-fed basis)

Item	Early finisher diets <sup>a</sup>						Late finisher diets <sup>b</sup>					
	Feather meal inclusion, %						Feather meal inclusion, %					
	0	2	4	6	8	10	0	2	4	6	8	10
Ingredient, %												
Corn	69.43	71.18	72.42	71.27	70.13	68.98	75.43	76.09	74.94	73.79	72.64	71.50
Soybean meal (48% CP)	24.38	20.14	16.42	15.19	13.95	12.72	18.69	15.58	14.34	13.11	11.88	10.64
Limestone	0.72	0.73	0.74	0.74	0.74	0.73	0.77	0.78	0.78	0.77	0.77	0.77
Dicalcium phosphate	0.99	1.01	1.02	1.01	1.01	1.01	0.76	0.77	0.76	0.76	0.75	0.75
Vitamins-minerals <sup>c</sup>	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Antibiotic <sup>d</sup>	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Feather meal <sup>e</sup>	—	2.00	4.00	6.00	8.00	10.00	—	2.00	4.00	6.00	8.00	10.00
Poultry fat	3.67	4.03	4.39	4.76	5.14	5.51	3.50	3.87	4.24	4.62	4.99	5.37
Lysine·HCL	0.01	0.11	0.21	0.22	0.23	0.25	0.05	0.13	0.14	0.15	0.17	0.18
DL-Methionine	—	—	0.01	0.01	0.01	0.01	—	—	—	—	—	—
Calculated composition												
Crude protein, %	17.35	17.30	17.40	18.44	19.47	20.51	15.18	15.53	16.56	17.6	18.63	19.67
Lysine, % <sup>f</sup>	0.75	0.75	0.75	0.75	0.75	0.75	0.65	0.65	0.65	0.65	0.65	0.65
Methionine, %	0.25	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.21	0.21	0.21	0.21
Sulfur amino acids, %	0.48	0.51	0.54	0.59	0.64	0.69	0.44	0.47	0.52	0.57	0.62	0.66
Threonine, %	0.49	0.49	0.50	0.53	0.57	0.61	0.42	0.43	0.47	0.51	0.54	0.58
Tryptophan, %	0.16	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12

<sup>a</sup>Diets were formulated to contain 3,500 kcal/kg of ME, 0.60% Ca, and 0.25% available P.

<sup>b</sup>Diets were formulated to contain 3,500 kcal/kg of ME, 0.55% Ca, and 0.20% available P.

<sup>c</sup>Supplied per kg of complete diet: 5,540 IU of vitamin A as retinyl acetate, 1,108 IU of vitamin D<sub>3</sub>, 22 IU of vitamin E as dl- $\alpha$ -tocopherol acetate, 1.98 mg of vitamin K as menadione dimethylpyrimidinol bisulfite, 165 mg of choline as choline chloride, 22 mg of niacin, 17.6 mg of d-pantothenic acid as dl-calcium pantothenate, 4.4 mg of riboflavin, 1.1 mg of pyridoxine as pyridoxine·HCl, 0.55 mg thiamine as thiamine mononitrate, 0.022 mg of vitamin B<sub>12</sub>, 0.33 mg of folic acid, 0.04 mg of d-biotin, 110 mg Zn as ZnSO<sub>4</sub>, 110 mg Fe as FeSO<sub>4</sub>, 22 mg Cu as CuSO<sub>4</sub>, 55 mg Mn as MnO, 0.28 mg I as EDDI, and 0.30 mg Se as NaSeO<sub>3</sub>.

<sup>d</sup>Supplied 55 mg of chlortetracycline/kg of complete diet.

<sup>e</sup>Hydrolyzed feather meal (Pilgrims Pride Eastern Division, Broadway, VA).

<sup>f</sup>Amino acids are expressed on a calculated ileal apparent digestible basis.

is greater than previous recommendations to limit the use of feather meal in growing-finishing pig diets to a maximum of 5% (Seerley, 1991). Combs et al. (1958) reported that commercial steam-hydrolyzed feather meal could be included in diets for pigs at a rate of 5% without supplementing additional lysine and that the inclusion rate could be increased to 7.5% when lysine was supplemented. Chiba et al. (1995) evaluated the use of feather meal as a source of nonspecific nitrogen, with the main objective to improve carcass quality. Pigs that were fed diets containing either 7.5 or 15% feather meal, replacing soybean meal on an equal lysine basis, had growth performance similar to that of their control counterparts. However, liver and kidney weights were increased in pigs fed feather meal diets, suggesting a larger contribution of visceral organ weight gain to the overall growth performance (Chiba et al., 1995). In a subsequent trial, Chiba et al. (1996) evaluated the inclusion of 0, 3, 6, 9, or 12% of feather meal in finishing pig (67.5 to 100.4 kg BW) diets. Growth and feed efficiency worsened as the inclusion of feather meal increased, but it appeared that an inclusion level of up to 9% was acceptable, which is in agreement with the present study. Different processing methods may affect the quality of the protein in feather meal, resulting in reduced digestibility and availability of amino acids to the pig and subsequent

reduction in growth performance (Papadopoulos, 1985). However, it appears that recommended inclusion rates for feather meal in swine diets are relatively consistent among research studies.

At the end of the grower period, pigs fed diets with 6% feather meal had greater ( $P < 0.05$ ) ultrasound backfat depth than pigs fed 2 or 4% feather meal, and pigs fed 2% feather meal had less ( $P < 0.05$ ) backfat depth than pigs fed 0, 6, 8, or 10% feather meal (Table 4). No differences in backfat measures ( $P > 0.10$ ) were observed between dietary treatments at the end of the trial (wk 16), although backfat increased numerically ( $P = 0.12$ ) with increasing levels of feather meal.

Loineye area measured by ultrasound was not affected ( $P > 0.10$ ) by dietary treatments during any of the measurement periods (Table 4). Percentage lean in the carcass was not altered ( $P > 0.12$ ) with feather meal inclusion in the diet; however, daily lean gain was reduced ( $P < 0.05$ ) in pigs fed 10% feather meal compared with pigs fed either 0, 2, 4, or 8% feather meal. This appeared to be due primarily to a reduction in growth rate, rather than a change in carcass composition.

Based on these results, carcass characteristics may be affected by feather meal inclusion level during different stages of the growth period. Diets for the present study were formulated to be isocaloric in ME con-

**Table 3.** Effects of feather meal inclusion rate on growth performance of grower-finisher pigs<sup>a</sup>

Item	Feather meal inclusion rate, %						SEM	P-value
	0	2	4	6	8	10		
Body weight, kg								
Week 0	23.2	23.2	23.2	23.2	23.2	23.2	—	—
Week 4	45.8	44.2	45.1	44.6	44.3	44.3	0.45	0.12
Week 8	71.1	70.7	71.1	69.7	69.5	68.7	0.74	0.14
Week 12	96.3	93.8	94.6	92.6	94.5	91.9	1.21	0.16
Week 16	122.0 <sup>b</sup>	119.2 <sup>bc</sup>	120.9 <sup>b</sup>	119.2 <sup>bc</sup>	120.6 <sup>b</sup>	115.8 <sup>c</sup>	1.50	0.10
Growing period								
ADG, kg	0.85	0.85	0.86	0.83	0.83	0.81	0.01	0.14
ADFI, kg	1.82	1.77	1.83	1.78	1.73	1.73	0.04	0.20
Gain/feed	0.470	0.481	0.469	0.468	0.479	0.472	0.005	0.42
Finishing period								
ADG, kg	0.91	0.87	0.89	0.89	0.91	0.84	0.02	0.23
ADFI, kg	2.65 <sup>b</sup>	2.59 <sup>bc</sup>	2.66 <sup>b</sup>	2.59 <sup>bc</sup>	2.62 <sup>b</sup>	2.43 <sup>c</sup>	0.06	0.10
Gain/feed	0.346	0.335	0.336	0.342	0.348	0.345	0.006	0.45
Overall								
ADG, kg	0.88 <sup>b</sup>	0.86 <sup>bc</sup>	0.87 <sup>b</sup>	0.86 <sup>bc</sup>	0.87 <sup>b</sup>	0.83 <sup>c</sup>	0.01	0.10
ADFI, kg	2.23 <sup>b</sup>	2.18 <sup>bc</sup>	2.24 <sup>b</sup>	2.18 <sup>bc</sup>	2.17 <sup>bc</sup>	2.08 <sup>c</sup>	0.04	0.09
Gain/feed	0.396	0.394	0.391	0.394	0.403	0.399	0.004	0.48

<sup>a</sup>Each value represents a mean of eight pens with five pigs each. Initial weight was used as a covariate in the data analysis.

<sup>b,c</sup>Means within a row with different superscripts differ ( $P < 0.05$ ).

tent and therefore an effect on carcass composition was not expected. However, if the energy value of feather meal was underestimated in this experiment, the energy content of the final diets may have been greater in diets containing feather meal. In addition, the calculated NE values of the experimental diets (NRC, 1998) were approximately 13 to 24 kcal/kg greater (depending on diet phase) for each incremental increase of feather meal inclusion. Therefore, the tendency for increased backfat levels observed in diets with greater levels of feather meal may be the result of greater dietary NE values. Similarly, Chiba et al. (1995) attempted to improve carcass quality in pigs by supplying excess dietary N and, therefore, effectively reducing the NE content of the diet. They reported

that providing excess N from either soybean meal or feather meal was effective in improving carcass traits of finisher pigs. Chiba et al. (1996) reported that up to 9% of feather meal could be included in diets for finishing pigs without negatively affecting carcass characteristics or lean accretion.

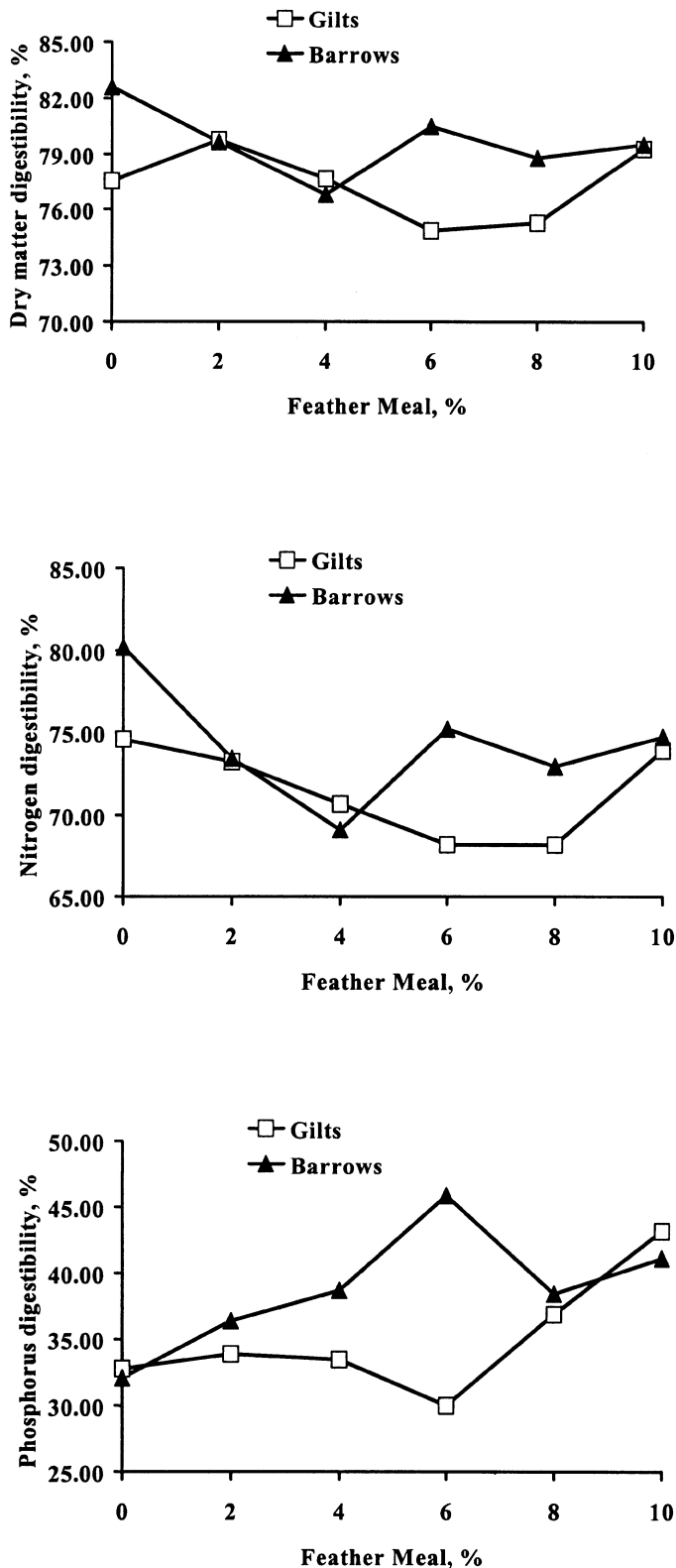
A sex  $\times$  feather meal interaction ( $P < 0.05$ ) was observed for DM digestibility (Figure 1). The response to feather meal was best described by a cubic relationship in gilts ( $P < 0.01$ ) with the greatest digestibility of DM in pigs fed 2 or 10% feather meal. In barrows, digestibility of DM tended to respond in a quadratic fashion ( $P < 0.10$ ), and diets containing 4% feather meal resulted in the lowest DM digestibility. The difference in DM digestibility in response to feather meal

**Table 4.** Effects of feather meal inclusion rate on ultrasound carcass characteristics of grower-finisher pigs<sup>a</sup>

Item	Feather meal inclusion rate, %						SEM	P-value
	0	2	4	6	8	10		
Backfat, mm								
Initial	6.62	6.42	6.21	6.66	6.55	6.84	0.21	0.39
Grower	11.90 <sup>bc</sup>	10.86 <sup>d</sup>	11.51 <sup>cd</sup>	12.49 <sup>b</sup>	12.02 <sup>bc</sup>	11.95 <sup>bc</sup>	0.33	0.03
Finisher	17.76	16.43	17.39	18.76	17.46	18.92	0.67	0.12
Loineye, cm <sup>2</sup>								
Initial	11.48	11.45	10.88	11.34	11.00	11.61	0.21	0.12
Grower	29.58	29.13	30.45	29.73	29.43	29.25	0.51	0.53
Finisher	44.68	45.39	43.76	44.49	45.67	45.19	0.88	0.69
Fat-free lean, %	51.8	52.5	51.6	51.5	52.2	51.6	0.35	0.25
Lean gain, g/d	344 <sup>b</sup>	341 <sup>b</sup>	339 <sup>b</sup>	332 <sup>bc</sup>	340 <sup>b</sup>	324 <sup>c</sup>	5	0.04

<sup>a</sup>Each value represents a mean of eight pens with five pigs each. Pig BW at the end of the grower or finisher phase was used as a covariate in the data analysis.

<sup>b,c,d</sup>Means within a row with different superscripts differ ( $P < 0.05$ ).



**Figure 1.** Digestibility of DM, N, and P in pigs fed different levels of feather meal. Sex  $\times$  feather meal interactions were observed for DM (SEM = 1.23;  $P < 0.05$ ) and P (SEM = 2.65;  $P < 0.05$ ). A feather meal effect was observed for N (SEM = 1.95;  $P < 0.05$ ).

**Table 5.** Odorous compounds in feces from pigs fed different levels of feather meal<sup>a</sup>

Item	Feather meal, %			SEM	<i>P</i> -value
	0	4	8		
Acetic acid	58.4	77.2	72.4	8.0	0.25
Propionic acid	35.8	47.3	85.4	20.2	0.22
Butanoic acid	19.7 <sup>b</sup>	32.1 <sup>bc</sup>	39.6 <sup>c</sup>	5.3	0.05
Pentanoic acid	6.1 <sup>b</sup>	8.0 <sup>bc</sup>	14.3 <sup>c</sup>	2.3	0.05
3-Methylbutanoic acid	1.6 <sup>b</sup>	1.6 <sup>b</sup>	4.0 <sup>c</sup>	0.6	0.02
3-Methylphenol	7.6 <sup>b</sup>	1.0 <sup>c</sup>	2.9 <sup>bc</sup>	2.0	0.09
4-Methylphenol	4.7 <sup>b</sup>	3.5 <sup>bc</sup>	3.3 <sup>c</sup>	0.5	0.10
Indole	0.19 <sup>b</sup>	0.07 <sup>c</sup>	0.05 <sup>c</sup>	0.04	0.05
3-Methylindole (skatole)	0.62	0.50	0.71	0.10	0.36
2-Methylindole	0.35	0.32	0.48	0.25	0.89
Decane	55.1 <sup>b</sup>	39.0 <sup>bc</sup>	15.2 <sup>c</sup>	10.0	0.04
Nonanal	24.6	23.0	12.9	10.3	0.69
Undecane	160.3	115.8	60.3	40.0	0.24
Dodecane	61.5	31.4	18.9	14.2	0.12
Tridecane	3.4	1.9	0.6	0.9	0.11
Tetradecane	5.1	0.6	1.2	2.4	0.37

<sup>a</sup>Each value represents the mean of eight observations.

<sup>b,c</sup>Means within a row with different superscripts differ ( $P < 0.05$ ).

between gilts and barrows is surprising and appeared to be primarily due to the difference observed at the 6% inclusion level. Nitrogen digestibility decreased quadratically ( $P < 0.001$ ) with increasing levels of feather meal. Fecal nitrogen excretion calculated from the N content of the diets, feed intake during the period in which digestibility measurements were made, and measured N digestibility increased linearly ( $P < 0.02$ ) with increasing levels of feather meal in the diet (data not shown). The ileal and fecal digestibility of N in feather meal has been reported to be 10% lower compared to that in soybean meal (Knabe et al., 1989), which is consistent with the results of the present study. The experimental diets in the present study contained approximately 4.2% less soybean meal for each incremental increase of feather meal up to 4%, but soybean meal was reduced by only 1.3% in diets with 6% or greater levels of feather meal as a result of least-cost formulation. Therefore, the quadratic decrease in DM and N digestibility observed may have been related to the level of soybean meal in the diets.

Phosphorus digestibility increased in a linear fashion ( $P < 0.02$ ) in both gilts and barrows. However, the improvement in digestibility with increasing levels of feather meal was more pronounced in barrows than in gilts (sex  $\times$  feather meal interaction,  $P < 0.05$ ). Calculated fecal P excretion decreased ( $P < 0.001$ ) with increasing levels of feather meal (data not shown). Diets were formulated based on available P values (NRC, 1998), which resulted in slightly lower total dietary P content in diets with feather meal (0.54, 0.53, 0.51, 0.53, 0.53, and 0.47% analyzed dietary P for diets containing 0 to 10% feather meal, respectively). This may in part explain the differences in P excretion we observed. In addition, the availability of P in

feather meal may be greater than the value reported by NRC (1998).

Hobbs et al. (1996) demonstrated that increasing the crude protein content of the diet could lead to an increase in the production of odorous compounds. Phenols and indoles arise from protein degradation and have been found in freshly voided feces (Spoelstra, 1977). Volatile fatty acids are produced mainly in feces from fiber and protein degradation (Spoelstra, 1979). Therefore, measurement of odorous compounds in feces may be a superior indicator of odor production, particularly because significant problems exist with air sampling methods and the fact that most odorous compounds appear to originate from feces (O'Neill and Phillips, 1992).

On wk 9 of the trial (phase 3 diets; contained 19.4, 18.9, and 21.6% CP for the 0, 4, and 8% feather meal treatments, respectively), fecal samples were obtained from at least two pigs per pen, pooled by pen, and analyzed for odorous compounds. Butanoic and pentanoic acid concentrations were greater ( $P < 0.05$ ) in feces from pigs fed 8% feather meal than in feces from control pigs (Table 5). The concentration of 3-methylbutanoic acid was greater ( $P < 0.05$ ) in feces from pigs fed 8% feather meal than in feces from pigs fed 0 or 4% feather meal. Inclusion of 4% feather meal reduced ( $P < 0.05$ ) the concentration of 3-methylphenol compared to control diets, and inclusion of 8% feather meal reduced ( $P < 0.05$ ) the concentration of 4-methylphenol and decane compared to the control diet. The concentration of indole was reduced ( $P < 0.05$ ) when 4 or 8% feather meal was included. Concentrations of other detectable compounds (acetic acid, propionic acid, 2-methylindole, 3-methylindole, nonanal, undecane, dodecane, tridecane, and tetradecane) were not affected ( $P > 0.11$ ) by dietary treatments. Compounds that were measured but not detected included 2-methyl propanoic acid, phenol, 4-ethylphenol, 3-ethylphenol, 2,6-bis(1,1-dimethylethyl)phenol, carbondisulfide, ethanethiol, dimethylsulfide, dimethylamine, butyrolactone, nonadecane, pentane, nonane, and 1-decene. In agreement with this study, Hobbs et al. (1996) reported greater concentrations of volatile fatty acids and branched-chain volatile fatty acids in slurry from pigs fed high-protein diets. In addition, they reported increased levels of 4-methylphenol (*p*-cresol), indole, and skatole in slurry from pigs fed high protein diets. However, Sutton et al. (1999) observed no differences in phenolic compounds or sulfur-containing compounds in feces from pigs fed either 10, 13, or 18% CP diets. In contrast to these studies, we reported reduced levels of 3-methylphenol in feces from pigs fed 4% feather meal, 4-methylphenol in feces from pigs fed 8% feather meal, and indole in feces from pigs fed 4 and 8% feather meal. This is surprising, because only the diet with 8% feather meal contained a greater level of protein. Hammond et al. (1989) reviewed the origin of odorous compounds in livestock waste and reported that phenolic compounds are produced from tyrosine

and phenylalanine, indole and skatole from tryptophan, and sulfides from the sulfur amino acids. Therefore, we expected these compounds to increase with increasing levels of feather meal inclusion. Sulfur-containing compounds can contribute significantly to odor because of their low odor detection threshold and their relatively high concentration in livestock waste. However, the sulfur-containing compounds we attempted to measure were not detected in fresh feces of pigs. Hobbs et al. (1996) reported that sulfides were produced primarily after a few days of anaerobic storage. In addition, sulfides could be detected primarily in the headspace and were not present at detectable quantities in the slurry (Hobbs et al., 1997) or in fresh feces (O'Neill and Phillips, 1992).

## Implications

Hydrolyzed feather meal appears to be an acceptable protein source for growing-finishing pigs and can be incorporated at 8% into diets that are properly formulated without negatively affecting growth performance or carcass characteristics. From an environmental perspective, N excretion in feces increases due to a reduction in fecal N digestibility, but P excretion appears to decrease with feather meal inclusion. Furthermore, odorous compounds in feces can be affected by the inclusion of hydrolyzed feather meal in diets of growing-finishing pigs; however, the exact impact of these changes on odor perception remains to be elucidated.

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