Evaluating pellet and meal feeding regimens on finishing pig performance, stomach morphology, and carcass characteristics[1,2]

J. A. De Jong,* J. M. DeRouchey,* M. D. Tokach,*
S. S. Dritz,† R. D. Goodband,*[3] J. C. Woodworth,* and M. W. Allerson‡

*Department of Animal Sciences and Industry, College
of Agriculture, and †Department of Diagnostic Medicine/Pathobiology, College of Veterinary
Medicine, Kansas State University, Manhattan 66506-0201; and ‡Holden Farms Inc., Northfield, MN 55057

ABSTRACT: A total of 2,100 pigs (PIC 327 × 1050; initially 31.2 kg BW) were used in a 118-d trial to determine the effects of pellet or meal feeding regimens on finishing pig growth performance, stomach morphology, and carcass characteristics. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments (14 pens/treatment with 25 pigs/pen). Pens were sorted by gender allowing for 7 barrow pens and 7 gilt pens per treatment. The same corn–soybean meal–based diets containing 15% dried distillers' grains with solubles were used for all treatments and fed in 5 phases. Phases were fed from d 0 to 28, 28 to 56, 56 to 84, 84 to 98, and 98 to 118. The 6 treatments included a meal or pelleted diet fed from d 0 to 118, a meal diet fed from d 0 to 70 followed by pellets from d 70 to 118, a pelleted diet fed from d 0 to 70 followed by a meal diet from d 70 to 118, or pellets and meal rotated every 2 wk starting with meal or pellets. On d 110, 4 pigs from each pen were harvested and stomachs collected, from which a combined ulcer and keratinization score was determined for each pig. Overall, there were no differences in ADG across feeding regimens. Pigs fed meal throughout had the greatest ($P < 0.05$) ADFI, whereas pigs fed pellets throughout had the lowest ($P < 0.05$), with all other treatments intermediate ($P < 0.05$). Pigs fed pelleted diets throughout had the greatest ($P < 0.05$) G:F, whereas pigs fed meal throughout had the worst G:F ($P < 0.05$), with all other treatments intermediate ($P < 0.05$). When pelleted diets were fed for the last 58 d or for the entire trial, the incidence of ulceration and keratinization increased ($P < 0.05$), whereas pigs fed meal for the last 58 d had a lower incidence ($P < 0.05$), with all other treatments intermediate ($P < 0.05$). Feeding pellets throughout increased ($P < 0.05$) the number of pigs removed per pen compared with all other treatments. Pig removals were determined by an on-site farm manager when pigs were at risk due to weight loss, health, or animal welfare concerns and needed to be separated from the general population. There were no differences for any carcass characteristics measured including HCW, carcass yield, backfat depth, loin depth, and percentage lean. In conclusion, feeding pelleted diets improved G:F but increased stomach ulceration and pig removals; however, rotating pellets and meal diets provided an intermediate G:F response and moderated stomach ulcerations compared with feeding only pellets.

Key words: finishing pig, growth, meal, pellet, stomach ulcer

---

J. Anim. Sci. 2016.94:4781–4788
doi:10.2527/jas2016-0461

INTRODUCTION

To improve finishing pig feed utilization and minimize wastage, many swine producers have changed to, or are considering, feeding diets in pellet form. However, due to feed mill limitations and logistics, many producers might not be able to continually feed pelleted diets to all of their pigs. Because many commercial or producer-owned mills do not have enough capacity to pellet all diets, they are left with the option

---

[1] Contribution number 16-207-J from the Kansas Agric. Exp. Stn., Manhattan, KS 66506-0210.

[2] This project was supported by the Agriculture and Food Research Initiative Competitive Grant number 2011-68004-30336 from the USDA National Institute of Food and Agriculture.

[3] Corresponding author: goodband@ksu.edu

Received March 11, 2016.
Accepted August 25, 2016.

to pellet only part or none of their feed. Currently, there is little data available to determine the best regimen for maximizing pig performance when feeding a limited amount of pelleted feed during the finishing period. From a health perspective, pelleting diets have been shown to increase the incidence of ulcers in finishing pigs, which can ultimately lead to increases in mortality (Friendship, 2004; Cappai et al., 2013). The effects of feeding pelleted feed for varying lengths of time or pulse feeding (switching between pelleted and meal diets) has been evaluated (Potter et al., 2010; Paulk and Hancock, 2015), but its effects on stomach morphology are unknown.

There are also increased feed processing costs associated with pelleting feed (Wondra et al., 1995b). These increased costs can be deemed acceptable only if growth performance is great enough to compensate for the added cost of pelleting or an increase in pig mortality. By determining when feeding pellets can maximize profitability, production decisions can be made when mill capacity limits feeding pelleted diets. Our hypothesis of the study was that by rotational feeding of pellet and meal diets, pork producers might realize the benefits of pelleting without increasing the incidence of gastric ulcers and associated pig removals sometimes observed with prolonged feeding of pellets. Therefore, the objective of the current trial was to determine the effects of pellet feeding regimens on finishing pig growth performance, stomach morphology, and carcass characteristics.

MATERIALS AND METHODS

Housing, Animals, and Diets

All practices and procedures used in this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee (3445). The study was conducted at a commercial research–finishing barn in Easton, MN. The barn was double curtain sided and pens had completely slatted flooring and deep pits for manure storage. Each pen was equipped with a 3-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer for ad libitum access to feed and water. Pigs were fed a common corn–soybean meal–formulated diet in meal form on entering the finisher until the beginning of the trial. For the duration of the trial, all feeders were adjusted weekly and after diet changes to a target of 60% feed pan coverage regardless of feed form. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of providing and measuring feed amounts for individual pens.

A total of 2,100 pigs (PIC 327 × 1050; initially 31.5 ± 0.13 kg BW) were used in a 118-d trial. Pens of pigs were balanced by initial BW and randomly allotted to 1 of 6 dietary treatments. There were 25 pigs per pen allowing for 0.67 m^2/pig and 14 pens (observations) per treatment. Pens were sorted by gender allowing for 7 barrow pens and 7 gilt pens per treatment. Diets were formulated to meet or exceed nutrient requirement estimates for pigs for the respective weight ranges (NRC, 2012). All diets were formulated on a standardized ileal digestible AA basin using ingredient nutrient values and standardized ileal digestible coefficients derived from

Table 1. Diet composition of experimental diets, Exp. 1 (as-fed basis)[1]

	Dietary phase				
Item	1	2	3	4	5
Ingredient, %					
Corn	61.11	67.78	72.36	73.82	84.33
Soybean meal (46.5% CP)	20.11	13.50	9.00	7.80	12.49
Choice white grease	1.00	1.00	1.00	1.00	1.00
Dried distillers' grains with solubles	15.00	15.00	15.00	15.00	–
Monocalcium phosphate (21% P)	0.25	0.15	0.10	0.00	0.25
Limestone	1.15	1.20	1.20	1.20	1.00
Salt	0.50	0.50	0.50	0.50	0.50
L-Lys HCl	0.43	0.44	0.44	0.38	0.21
DL-Met	0.07	0.04	0.02	–	–
L-Thr	0.10	0.10	0.09	0.07	0.06
L-Trp	0.03	0.04	0.04	0.03	0.01
Vitamin and trace mineral premix[2,3]	0.25	0.25	0.25	0.20	0.15
Total	100	100	100	100	100
Calculated analysis					
Standard ileal digestible (SID) AA, %					
Lys	1.05	0.90	0.79	0.71	0.65
Ile:Lys ratio	61	59	58	61	66
Met:Lys ratio	33	32	31	32	31
Met + Cys:Lys ratio	58	58	58	61	62
Thr:Lys ratio	62	62	62	64	67
Trp:Lys ratio	19.0	19.0	19.0	19.0	19.0
Val:Lys ratio	70	70	70	75	78
Total Lys, %	1.20	1.03	0.91	0.83	0.75
ME,[4] kcal/kg	3,332	3,337	3,342	3,347	3,376
NE,[4] kcal/kg	2,502	2,541	2,570	2,575	2,594
SID Lys:ME ratio, g/Mcal	3.15	2.70	2.36	2.12	1.92
CP, %	19.0	16.5	14.8	14.2	13.0
Crude fiber, %	3.3	3.2	3.1	3.1	2.2
Ca, %	0.58	0.56	0.53	0.51	0.49
P, %	0.44	0.39	0.36	0.34	0.36
Available P, %	0.18	0.15	0.13	0.11	0.10

[1] Phase 1 diets were fed from d 0 to 28, Phase 2 from 28 to 56, Phase 3 from 56 to 84, Phase 4 from d 84 to 98, and Phase 5 from d 98 to 118.

[2] Provided, per kilogram of premix, 4,537,205 IU vitamin A, 1,088,929 IU vitamin D_3, 19,963 IU vitamin E, 2,117 mg vitamin K, 2,722 mg riboflavin, 12,704 mg pantothenic acid, 16,334 mg niacin, and 18.1 mg vitamin B_{12}. Provided, per kilogram of premix, 53.3 g Mn from manganese oxide, 134 g Fe from iron sulfate, 160 g Zn from zinc sulfate, 13 g Cu from copper sulfate, and 137 mg I from calcium iodate.

[3] Quantum Blue 5 G (AB Vista, Marlborough, UK) provided 455 phytase units/kg diet, with a release of 0.12% available P.

[4] NRC (2012).

Figure 1. Esophageal opening of stomach with no keratinization or ulceration (keratinization score of 1 and ulcer score of 1 for an ulcer index score of 2). Keratinization and ulceration were scored by a single person at the time of slaughter from 4 pigs in each pen. Keratinization scores were assigned on a scale from 1 to 4 with 1 being normal or no keratinization of the esophageal region (as shown above), 2 being keratin covering <25% of the esophageal region, 3 being keratin covering 25 to 75% of the esophageal region, and 4 being keratin covering >75% of the esophageal region. Ulcer scores were also assigned on a scale from 1 to 4 with 1 being no ulcers present, 2 being ulceration affecting <25% of the esophageal region, 3 being ulceration affecting 25 to 75% of the esophageal region, and 4 being ulceration affecting >75% of the esophageal region. An index of stomach morphology was developed by adding a pig's ulcer and keratinization scores. An additional score of 4 was added to each pig that had an ulceration score greater than 1.

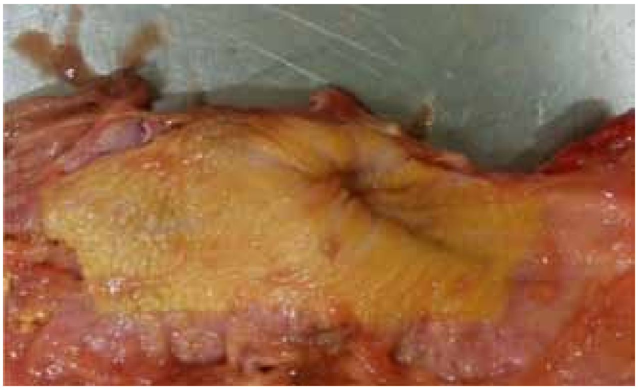

Figure 2. Esophageal opening of stomach with 100% keratinization and no ulceration (ulcer index score of 5). Keratinization and ulceration were scored by a single person at the time of slaughter from 4 pigs in each pen. Keratinization scores were assigned on a scale from 1 to 4 with 1 being normal or no keratinization of the esophageal region, 2 being keratin covering <25% of the esophageal region, 3 being keratin covering 25 to 75% of the esophageal region, and 4 being keratin covering >75% of the esophageal region (see above). Ulcer scores were also assigned on a scale from 1 to 4 with 1 being no ulcers present (see above), 2 being ulceration affecting <25% of the esophageal region, 3 being ulceration affecting 25 to 75% of the esophageal region, and 4 being ulceration affecting >75% of the esophageal region. An index of stomach morphology was developed by adding a pig's ulcer and keratinization scores. An additional score of 4 was added to each pig that had an ulceration score greater than 1.

NRC (2012) with the exception for the DDDS where values from Stein and Shurson (2009) were used (Table 1). The same corn–soybean meal–based diets containing 15% DDGS were used for all treatments and fed in 5 phases. Dried distillers' grains with solubles were removed from the diet during the fifth phase. Phases were fed from d 0 to 28, 28 to 56, 56 to 84, 84 to 98, and 98 to 118. The 6 treatments included a meal or pelleted diet fed from d 0 to 118, a meal diet fed from d 0 to 70 and pellets fed from d 70 to 118, a pelleted diet fed from d 0 to 70 and a meal diet fed from d 70 to 118, or pellets and meal rotated every 2 wk starting with meal and ending with pellets or starting with pellets and ending with meal. Pens of pigs were weighed approximately every 2 wk and feed disappearance was measured to determine ADG, ADFI, and G:F. Pig removals were determined by an on-site farm manager when pigs were at risk due to weight loss, health, or animal welfare concerns and needed to be separated from the general population. If a pig was removed from the study, the pig was weighed at the time of removal and the weight was accounted for in the growth performance from the period in which the pig was removed. This procedure was also used for pigs marketed prior to the conclusion of the trial on d 110 (at approximately 135 kg). Pig days (number of pigs per pen × days on test) were used to adjust ADFI and ADG for the pen at the end of each weigh period, such that a removal's pig days were added back in to the total pig days for the pen for that weigh period.

On d 110, pens of pigs were weighed and 4 randomly selected pigs (2 barrows and 2 gilts) from each pen were weighed and transported to Natural Food Holdings (Sioux Center, IA). Pigs had continual access to feed except during transportation. Pigs were harvested and each stomach was collected. Stomachs were then assigned an ulcer and keratinization score, which was determined by visual inspection by a single person (J. A. De Jong) at the time of slaughter using a scoring system outlined by Paulk et al. (2015). Briefly, keratinization scores were assigned on a scale from 1 to 4 with 1 being normal or no keratinization of the esophageal region (Fig. 1), 2 being keratin covering <25% of the esophageal region, 3 being keratin covering 25 to 75% of the esophageal region, and 4 being keratin covering >75% of the esophageal region (Fig. 2). Ulcer scores were also assigned on a scale from 1 to 4 with 1 being no ulcers present, 2 being ulceration affecting <25% of the esophageal region, 3 being ulceration affecting 25 to 75% of the esophageal region, and 4 being ulceration affecting >75% of the esophageal region (Fig. 3). An index of stomach morphology was developed by adding a pig's ulcer and keratinization score. An additional score of 4 was added to each pig that had an ulceration score greater than 1. Because the keratinization and ulcer score were inversely related, this was done to differentiate pigs with a high ulcer score but low keratinization score having combined scores similar to pigs with a high keratinization score but low ulceration score. As ulcer scores increased, keratinization scores decreased due to tissue progressively moving from being keratinized to being ulcerated. Pigs with a high ulceration score but low keratinization score were assumed to have

Figure 3. Esophageal opening of stomach with 100% ulceration (ulcer index score of 9). Keratinization and ulceration were scored by a single person at the time of slaughter from 4 pigs in each pen. Keratinization scores were assigned on a scale from 1 to 4 with 1 being normal or no keratinization of the esophageal region, 2 being keratin covering <25% of the esophageal region, 3 being keratin covering 25 to 75% of the esophageal region, and 4 being keratin covering >75% of the esophageal region (see above). Ulcer scores were also assigned on a scale from 1 to 4 with 1 being no ulcers present (see above), 2 being ulceration affecting <25% of the esophageal region, 3 being ulceration affecting 25 to 75% of the esophageal region, and 4 being ulceration affecting >75% of the esophageal region. An index of stomach morphology was developed by adding a pig's ulcer and keratinization scores. An additional score of 4 was added to each pig that had an ulceration score greater than 1.

worse stomach morphology, as ulceration is a product of keratinization and represents a stomach with a more progressed case of esophageal deterioration. Therefore, this index was developed so that a high score represents a stomach with more damage present from keratinization and ulceration. Before final marketing, all pigs were individually weighed and tattooed for carcass data collection. On d 112 (barrows) and 118 (gilts) of the trial, all remaining pigs were transported 246 km to a commercial packing plant (Tyson Foods, Waterloo, IA) for harvest. Standard carcass characteristics including HCW, carcass yield (calculated from HCW and farm weight), and percentage lean (lean % = 48.3575 − (6.38916 × backfat, mm) + (4.424677 × loin depth, mm)) were measured and calculated using National Pork Producers Council (2001) procedures. Fat depth and loin depth were measured with an optical probe (SFK Technology, Herlev, Denmark) inserted between the third and fourth ribs of the right side of the carcass located anterior to the last rib at a distance approximately 7 cm from the dorsal midline.

All diets were manufactured at a commercial feed mill (Hubbard Feeds, Mankato, MN). Diets were pelleted with a 280-horsepower pellet mill (7800 HD Master Model; California Pellet Mill, San Francisco, CA), using a 4-mm die. Diets were conditioned at approximately 74°C for 45 s.

Physical Diet Analysis

Samples of corn, soybean meal, and DDGS were collected at the mill along with samples of each diet between each feeding period and were blended within phase and subsampled. All ingredient and feed samples were analyzed for DM (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), ether extract (method 920.39 A; AOAC, 2006), Ca (method 965.14/985.01; AOAC, 2006), P (method 965.17/985.01; AOAC, 2006), starch (method 996.11; AOAC, 2006), and ADF and NDF (Van Soest et al., 1991) by Ward Laboratories, Inc. (Kearney, NE). Analysis of the corn, soybean meal, and DDGS used during the experiment revealed that nutrient values were similar to those used in formulation (Tables 1 and 2). Nutrient analysis of the treatment diets showed that all of the nutrients were also similar to formulated values (Table 3).

Table 2. Chemical analysis of ingredients (as-fed basis)[1]

Item	Corn[2]	Soybean meal	Dried distillers' grains with solubles[3]
DM, %	88.87	91.05	90.68
CP, %	9.1 (8.2)	45.1 (46.5)	29.8 (27.7)
ADF, %	3.0	6.3	10.1
NDF, %	6.1	7.4	24.8
Ca, %	0.05 (0.02)	0.41 (0.33)	0.15 (0.20)
P, %	0.29 (0.26)	0.74 (0.71)	0.81 (0.77)
Ether extract, %	3.1 (3.5)	1.8 (1.5)	8.7 (7.3)
Starch, %	60.7	4.0	3.7

[1] A composite sample of 3 subsamples taken throughout the experiment at the feed mill were used for analysis.

[2] Values in parenthesis for corn and soybean meal were taken from the NRC (2012).

[3] Values in parenthesis for dried distillers' grains with solubles are taken from Stein and Shurson (2009).

Particle size of the diets (before pelleting) was determined using Tyler sieves (W.S. Tyler, Mentor, OH 44060), with numbers 6, 8, 10, 14, 20, 28, 35, 48, 65, 100, 150, 200, and 270 and a pan. A Ro-Tap sieve shaker (W.S. Tyler, Mentor, OH) was used to sift the 100-g samples for 10 min. A geometric mean particle size and the log normal SD were calculated by measuring the amount of grain remaining on each screen (ASAE, 2008). No flow agent was used for particle size analysis. Particle size of the meal diets in the current study ranged from 641 to 714 μm across all phases.

For pelleted diets, pellet durability index was determined using a Holmen NHP100 (Tekpro Limited, Norfolk, UK). Percentage fines were characterized as material that would pass through a number 6 Tyler Sieve (3,360-μm opening; W.S. Tyler) during 15 s of manual shaking (ASAE, 1987). Percentage fines was lowest and pellet durability index highest during the last phase when DDGS were removed from the diet. The improvement in pellet quality when DDGS were removed from the diet was expected and is similar to observations from Fahrenholz (2008), who observed that when DDGS were added at greater than 10% of the diet, pellet quality was negatively affected.

Table 3. Chemical analysis of diets (as-fed basis)[1,2]

	Dietary phase				
Item	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
DM, %	90.90	90.43	89.92	90.19	89.39
CP, %	19.1	16.5	15.3	14.8	12.6
ADF, %	4.3	3.5	4.7	3.8	1.9
NDF, %	10.1	10.6	11.6	11.0	8.6
Ca, %	0.64	0.56	0.53	0.50	0.57
P, %	0.45	0.42	0.40	0.36	0.35
Ether extract, %	4.8	4.9	5.2	4.9	4.2
Starch, %	39.6	42.7	43.6	45.9	51.2
Particle size, µm	683	692	705	714	641
Particle size SD	2.16	2.16	2.17	2.04	2.33
Pellet fines, %	26.7	34.6	20.3	33.1	3.7
PDI,[3] %	84.5	85.8	86.9	90.2	94.5

[1] A composite sample consisting of 6 subsamples was used for analysis.

[2] Meal and pelleted diet samples within phase were individually analyzed and the results were averaged. Particle size represents the complete meal diet for each phase. Percentage fines and pellet durability index represent the pelleted diet for each phase.

[3] PDI = pellet durability index.

Statistical Analysis

Data were analyzed as a completely randomized design using the PROC GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. The model included the fixed effect of treatment and gender and their interaction. All distributions were assumed to be normal with the exception of the keratinization score, ulcer score, and pigs removed per pen. These criteria were modeled assuming a negative binomial distribution on the response. Overdispersion for the negative binomial responses was assessed using a maximum-likelihood-based Pearson χ^2/df statistic. For those criteria, a normal distribution was assumed and was checked using standard diagnostics on Studentized residuals. Furthermore, for HCW, backfat, loin depth, and lean, individual carcass data was collected and a random effect of the cross product of pen and treatment was included in the statistical model. Pairwise comparison of means was used to determine differences among treatments using the diff option of the LSMEANS statement. These pairwise comparisons were protected by the overall treatment P-value at a value $P \leq 0.05$. Results were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Growth and Carcass

Overall, there were no differences for ADG when pigs were fed a meal or pelleted diet (Table 4). However, the vast majority of research comparing meal and pelleted diets in finishing pigs has shown significant or numerical improvements in ADG when pigs are fed pelleted diets (Skoch et al., 1983; Wondra et al., 1995a,b; Potter et al., 2010). The lack of an improvement in ADG in pigs fed pelleted diets may be a result of worsened stomach morphology as indicated by the ulcer index scores. The results in the present study agree with observations of Elbers et al. (1995), where it appears that the expected improvement in ADG from pelleting may have been negatively affected due to the increased incidence of ulceration. This would also agree with work by Ayles et al. (1996), who showed that as ulcer severity increased, ADG decreased in finishing pigs.

Pigs fed meal throughout the experiment had the greatest ($P < 0.05$) ADFI compared with all other treatments. Pigs fed pelleted diets throughout had decreased ($P < 0.05$) ADFI relative to pigs fed the regimen starting with meal and then rotated pellets and meal every 2 wk, with all other treatments intermediate. Wondra et al. (1995b) observed that pigs fed a pelleted diet had reduced intake when compared with pigs fed a meal diet. The decrease in feed intake from feeding a pelleted diet may be a result of feed wastage being limited, as noted by Hanrahan (1984), or as a result of the improved digestibility of a pelleted diet (Skoch et al., 1983). Improvements in digestibility or less feed wastage would also explain why pigs fed pelleted diets throughout had the most improved ($P < 0.05$) G:F whereas pigs fed meal throughout had the worst G:F ($P < 0.05$) and all other treatments were intermediate ($P < 0.05$). Improvements in G:F from pelleting diets has been widely shown throughout the literature (Stark et al., 1994; Myers et al., 2013; De Jong et al., 2013).

Paulk and Hancock (2015) fed pellets and meal diets to finishing pigs in a 2-phase study. Pigs were given either pellets or meal for the entire period, pellets for the first half of finishing (time basis) and meal for the second half, or meal for the first half of finishing (time basis) and pellets for the second half. The authors noted that pigs fed pellets for the duration of the study tended to have the most improved ADG and G:F, pigs fed meal had the worst, and pigs fed pellets for only part of the grow–finish phase had intermediate ADG and G:F. In the current experiment, the timing of when pigs received pellets or switching back and forth did not influence G:F. When pellets and meal were rotated every 2 wk in the study herein, G:F was improved from 5 to 13% during each 2-wk weigh period that pellets were fed (Fig. 4) compared with those pigs fed meal during the same 2-wk period.

Pigs fed a pelleted diet throughout the trial had an increased ($P < 0.05$) number of pigs removed per pen compared with all other treatments. When pelleted diets were fed for the last 58 d or for the entire trial, the ulcer index increased ($P < 0.05$) relative to

Table 4. The effect of pellet feeding regimen on finishing pig growth performance, carcass characteristics, and stomach morphology[1]

	Diet form and period, d 0 to 70/d 70 to 118						
	Meal	Pellet	Meal	Pellet	Rotated[2]	Rotated[3]	
Item,	Meal	Pellet	Pellet	Meal	Rotated	Rotated	SEM
BW, kg							
d 0	31.5	31.6	31.4	31.4	31.6	31.5	0.60
Final wt[4]	135.6	136.6	136.0	134.0	135.3	136.2	1.95
d 0 to 118							
ADG, kg	0.96	0.97	0.96	0.96	0.96	0.97	0.012
ADFI, kg	2.36^{a}	2.26^{c}	2.30^{bc}	2.28^{bc}	2.30^{b}	2.29^{bc}	0.024
G:F	0.407^{c}	0.430^{a}	0.421^{b}	0.422^{b}	0.420^{b}	0.423^{b}	0.002
Pigs removed/pen	0.50^{b}	1.92^{a}	1.06^{b}	0.93^{b}	0.85^{b}	0.92^{b}	0.265
Keratinization score	2.3	2.4	2.2	2.1	2.8	2.1	0.22
Ulceration score	1.5	2.0	2.2	1.6	1.8	1.6	0.20
Ulcer index[5]	5.25^{ab}	6.72^{a}	6.72^{a}	4.61^{b}	6.15^{ab}	5.32^{ab}	0.61
Carcass characterisitcs							
HCW, kg	97.9	99.2	98.6	97.9	98.4	98.9	1.06
Yield, %	74.8	75.2	74.7	74.8	75.3	75.6	0.50
Backfat, mm	16.7	17.1	16.8	16.5	16.8	16.8	0.26
Loin depth, mm	72.8	73.8	73.9	73.4	73.7	73.9	0.36
Lean, %[6]	56.3	56.2	56.2	56.5	56.5	56.3	0.19

$^{a–c}$Superscripts within a row are different ($P < 0.05$).

[1] A total of 2,100 pigs (PIC 327 × 1050; initially 31.5 ± 0.13 kg BW) were used in a 118-d trial; there were 25 pigs per pen and 14 pens per treatment (7 barrows and 7 gilts).

[2] Meal and pellet were rotated every 2 wk starting with meal and ending with pellet. Pigs were fed a meal diet for 10 d prior to collecting stomach morphology scores.

[3] Meal and pellet were rotated every 2 wk starting with pellet and ending with meal. Pigs were fed a pelleted diet for 10 d prior to collecting stomach morphology scores.

[4] On d 110, 4 pigs (2 barrows and 2 gilts) were removed from each pen and a combined keratinization and ulceration score was assigned to each stomach. On day 112 all barrows were marketed (7 pens per treatment). On day 118, all gilts were marketed (7 pens per treatment).

[5] An index of stomach morphology was developed by adding a pig's ulcer and keratinization score. An additional score of 4 was added to each pig that had an ulceration score greater than 1.

[6] Calculated using the equation lean % = 48.3575 − (6.38916 × backfat, mm) + (4.424677 × loin depth, mm).

pigs fed meal for the last 58 d, with all other treatments intermediate. This is similar to Flatlandsmo and Slagsvold (1971) and Wondra et al. (1995b), who both reported that pelleting diets increased the incidence of ulcers in finishing pigs. It appears that continuously feeding a pelleted diet increased the ulceration index, which led to an increased number of pigs needing to be removed from the study. Mößeler et al. (2012) observed that pigs fed pellets had a more liquid chyme and increased ulceration. The increase in fluidity of the stomach contents appears to lead to increased incidences of ulceration. Dirkzwager et al. (1998) and Mößeler et al. (2014) noted that the pH of the stomach was more consistent in all 4 regions when compared with pigs fed a coarse meal diet. This may indicate that there is increased mixing of stomach contents when a pelleted diet is fed, most likely as a result of the increased fluidity of the stomach contents. Another factor to consider is that the last dietary phase (phase 5) did not contain 15% DDGS as had the previous 4 phases. This was done to reduce the negative impact of the DDGS on carcass yield and fat iodine value but may have increased the fluidity of the stomach contents. Dirkzwager et al. (1998) observed that pigs fed a diet with added fiber had a reduced incidence of gastric ulcers compared with those fed a diet without added fiber. Although all pigs in the present study were fed identical diets during each phase of the study, it should be noted that pigs were fed a diet lower in ADF and NDF (no DDGS) in the last phase of the study compared with those in previous dietary phases.

It was observed in the current study that pigs fed a meal diet for the second half of the trial had a decreased ($P < 0.05$) stomach ulcer index score compared with pigs fed pellets for the entirety or the second half of the trial. Ayles et al. (1996) were able to demonstrate that feeding a coarse ground meal diet for as little as a 3-wk period can improve stomach morphology when a finely ground diet was previously fed. Although both the meal and pelleted diets were from the same corn source and had identical particle sizes, it is possible that the pelleting process may further decrease the

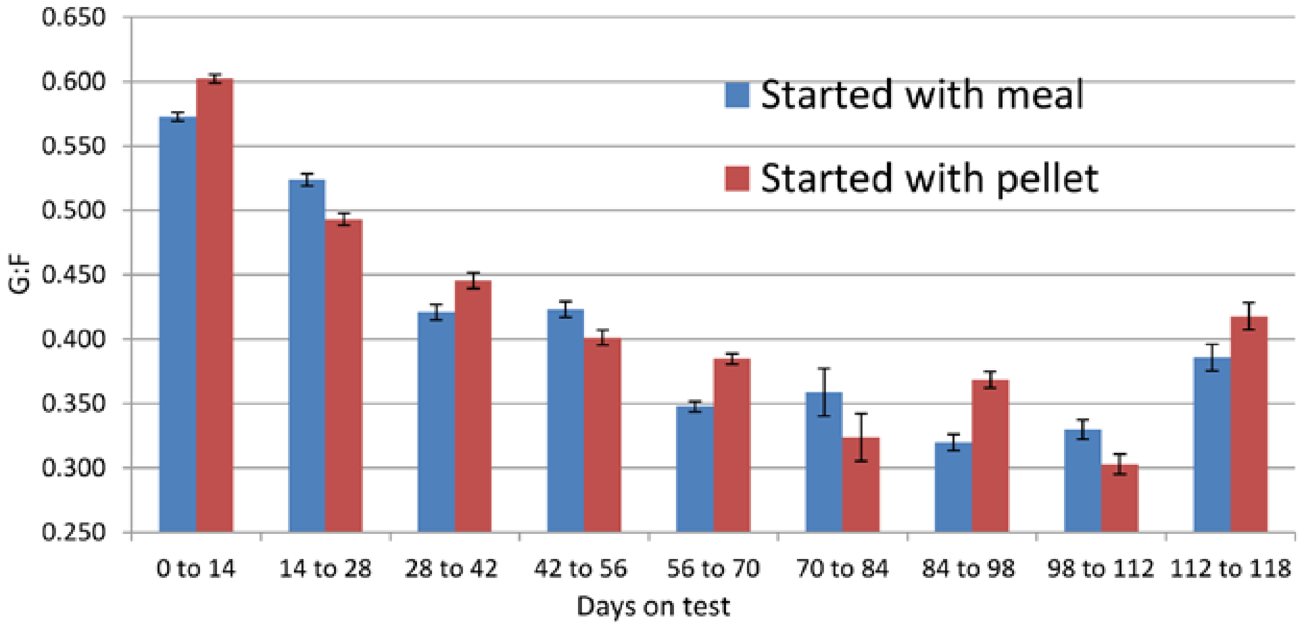

Figure 4. Effect of rotating meal and pellet every 2-wk on G:F. Data demonstrate the improvement in G:F when pigs were fed pelleted diets during 2 wk intervals and poorer G:F when fed the meal-based diets. Treatments were significantly different (P < 0.05) at every weigh period. From d 112 to 118 only gilts remained in the experiment explaining the improvement in G:F for the last period.

particle size of the diet. Previous reports have shown reductions in diet particle size of 50 to 290 μm during pelleting (Svihus et al., 2004). Further particle size reduction of the diet during pelleting could have resulted in a smaller particle size of the pelleted diet, which may have contributed to the ulceration from pelleting. The possibility of a finer grind in the pelleted diet of the current study provides some reasoning as to why stomach morphology scores worsened when pigs were fed pellets.

Paulk and Hancock (2015) switched from meal to pelleted diets fed to finishing pigs and also observed no differences in carcass characteristics. Nemechek et al. (2016) observed no significant differences in any carcass measurements when pigs were fed a pelleted diet compared with a meal diet. However, Potter et al. (2010) observed that pigs fed a pelleted diet had improved carcass yield, but a tendency for decreased percentage lean and loin depth. The differences in carcass characteristics observed by Potter et al. (2010) may be attributed to the greater weight of the pigs fed pelleted diets compared with those fed meal-based diets.

In conclusion, our data suggest that if a meal diet is rotated with pelleted diets during the finishing period, ulceration of the stomach lining may be lessened and improvements from pelleting can still be realized. Feeding a pelleted diet improved G:F but also increased the number of pigs removed during the study as a possible result of stomach ulceration.

LITERATURE CITED

American Society of Agricultural Engineers (ASAE). 1987. Wafers, pellets, and crumbles – Definitions and methods for determining density, durability, and moisture content. ASAE standard S269.3, agricultural engineers yearbook of standards. ASAE, St. Joseph, MI.

American Society of Agricultural Engineers (ASAE). 2008. Method of determining and expressing fineness of feed materials by sieving. ASAE standard S319.4, agricultural engineers yearbook of standards. ASAE, St. Joseph, MO.

AOAC. 2006. Official methods of analysis. 18th ed. AOAC Int., Washington, DC.

Ayles, H. L., R. M. Friendship, and R. O. Ball. 1996. Effect of dietary particle size on gastric ulcers, assessed by endoscopic examination, and relationship between ulcer severity and growth performance of individually fed pigs. J. Swine Health Prod. 4:211–216.

Cappai, M. G., M. Picciau, and W. Pinna. 2013. Ulcerogenic risk assessment of diets for pigs in relation to gastric lesion prevalence. BMC Vet. Res. 9:36. doi:10.1186/1746-6148-9-36

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, R. D. Goodband, S. S. Dritz, and J. L. Nelssen. 2013. Effects of corn particle size, complete diet grinding, and diet form on pig growth performance, caloric efficiency, and carcass characteristics. J. Anim. Sci. 91(Suppl. 2):70 (Abstr.)

Dirkzwager, A., A. R. W. Elbers, P. J. van der Aar, and J. H. Vos. 1998. Effect of particle size and addition of sunflower hulls to diets on the occurrence of oesohagogastric lesions and performance in growing-finishing pigs. Livest. Prod. Sci. 56:53–60. doi:10.1016/S0301-6226(98)00143-2

Elbers, A. R., M. J. Hessing, M. J. Tielen, and J. H. Vos. 1995. Growth and oesophagogastric lesions in finishing pigs offered pelleted feed ad libitum. Vet. Rec. 136:588–590. doi:10.1136/vr.136.23.588

Fahrenholz, A. C. 2008. The effects of DDGS inclusion on pellet quality and pellet mill performance. MS Thesis, Kansas State Univ., Manhattan, KS

Flatlandsmo, K., and P. Slagsvold. 1971. Effect of grain particle size and pellets on development of gastric ulcers in swine. J. Anim. Sci. 33:1263–1265. doi:10.2527/jas1971.3361263x

Friendship, R. M. 2004. Gastric ulceration in swine. J. Swine Health Prod. 12:34–35.

Hanrahan, T. J. 1984. Effect of pellet size and pellet quality on pig performance. Anim. Feed Sci. Technol. 10(4):277–283. doi:10.1016/0377-8401(84)90023-3

Mößeler, A. K., M. F. Wintermann, S. J. Sander, and J. Kamphues. 2012. Effect of diet grinding and pelleting fed either dry or liquid feed on dry matter and pH in the stomach of pigs and the development of gastric ulcers. J. Anim. Sci. 90:343–345. doi:10.2527/jas.53772

Mößeler, A. K., M. F. Wintermann, M. Beyerbach, and J. Kamphues. 2014. Effects of grinding intensity and pelleting of the diet – fed either dry or liquid – on intragastric milieu, gastric lesions, and performance of swine. Anim. Feed Sci. Tech. 194:113–120. doi:10.1016/j.anifeedsci.2014.05.005

Myers, A. J., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and J. L. Nelssen. 2013. The effects of diet form and feeder design on the growth performance of finishing pigs. J. Anim. Sci. 91:3420–3428. doi:10.2527/jas.2012-5612

National Pork Producers Council. 2001. Pork composition and quality assessment procedures. National Pork Producers Council, Des Moines, IA.

Nemechek, J. E., M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, and J. C. Woodworth. 2016. Effects of diet form and corn particle size on growth performance and carcass characteristics of finishing pigs. Anim. Feed Sci. Technol. 214:136–141. doi:10.1016/j.anifeedsci.2016.02.002

NRC. 2012. Nutrient requirements of swine. 11th ed. Natl. Acad. Press, Washington, DC.

Paulk, C. B., and J. D. Hancock. 2015. Effects of an abrupt change between diet form on growth performance in finishing pigs. Anim. Feed Sci. Technol. 211:132–136. doi:10.1016/j.anifeedsci.2015.10.017

Paulk, C. B., J. D. Hancock, A. C. Fahrenholz, J. M. Wilson, L. J. McKinney, K. C. Benhke, and J. C. Nietfeld. 2015. Effects of feeding cracked corn to nursery and finishing pigs. J. Anim. Sci. 93:1710–1720. doi:10.2527/jas.2014-8600

Potter, M. L., S. S. Dritz, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, J. L. Nelssen, and J. A. Barnes. 2010. Effects of meal or pellet diet form on finishing pig performance and carcass characteristics. J. Anim. Sci. 88(E-Suppl. 3):181. (Abstr.)

Skoch, E. R., S. F. Biner, C. W. Deyoe, G. L. Allee, and K. C. Behnke. 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. 57:922–928. doi:10.2527/jas1983.574922x

Stark, C. R., K. C. Behnke, J. D. Hancock, S. L. Traylor, and R. H. Hines. 1994. Effect of diet form and fines in pelleted diets on growth performance of nursery pigs. J. Anim. Sci. 72(Suppl. 1):24 (Abstr).

Stein, H. H., and G. C. Shurson. 2009. The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292–1303. doi:10.2527/jas.2008-1290

Svihus, B., K. H. Kløvstad, V. Perez, O. Zimonja, S. Sahlström, R. B. Schüller, W. K. Jeksrud, and E. Prestløkken. 2004. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. Anim. Feed Sci. Technol. 117:281–293. doi:10.1016/j.anifeedsci.2004.08.009

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Wondra, K. J., J. D. Hancock, K. C. Behnke, and C. R. Stark. 1995a. Effects of mill type and particle size uniformity on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:2564–2573. doi:10.2527/1995.7392564x

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines, and C. R. Stark. 1995b. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. 73:757–763. doi:10.2527/1995.733757x