Effects of two feeder designs and adjustment strategies on the growth performance and carcass characteristics of growing–finishing pigs[1,2]

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ABSTRACT: Our objective was to compare effects of a conventional dry (CD, 152.4-cm-wide, 5-space, Staco Inc., Schaefferstown, PA) and a wet–dry (WD, double-sided, each side = 38.1-cm-space, Crystal Springs, GroMaster Inc., Omaha, NE) feeder using various feeder adjustment openings on the growth performance and carcass characteristics of growing–finishing pigs (*Sus scrofa*). In Exp. 1, 1,296 pigs (BW 19 kg) were used in a 27-d study to evaluate 3 feeder openings nested within each feeder design. From d 0 to 27, pigs fed with a WD feeder had similar ADG, but lower ($P < 0.02$) ADFI and greater G:F than pigs fed with a CD feeder. Increased adjustment opening increased (linear, $P < 0.01$) ADG and ADFI by pigs fed with a WD feeder, and increased (linear, $P < 0.01$) ADFI by pigs fed with a CD feeder. In Exp. 2, 1,248 pigs (BW 33 kg) were used to evaluate 3 feeder openings nested within each feeder design in a 93-d study. Pigs fed with a WD feeder had greater ($P < 0.05$) ADG, ADFI, final BW, HCW, and backfat, but decreased fat-free lean index (FFLI) than those fed with a CD feeder. Increased opening of the WD feeder resulted in greater (linear, $P < 0.05$) ADG, ADFI, HCW, and backfat, but lower FFLI. No differences among CD feeder openings were observed, and G:F did not differ among all feeder treatments. In Exp. 3, 1,287 pigs (BW 38 kg) were used in a 92-d factorial experiment with 4 feeder treatments and 2 diet types (low and high byproduct diets). Feeder treatments were CD at approximately a 2.4-cm opening, WD at a 3.2-cm opening, WD changed to a 2.5-cm opening on d 56, and WD changed to a 2.5-cm opening on d 28 and a 1.9-cm opening on d 56. Pigs fed with a WD feeder had greater ($P < 0.01$) ADG, ADFI, HCW, and backfat, but decreased FFLI than pigs fed with a CD feeder. Decreasing the WD feeder opening during the study decreased ($P < 0.05$) ADG. Pigs with the WD feeder opening decreased to 1.9 cm had reduced ($P < 0.05$) ADFI and backfat, but increased FFLI compared with pigs with a WD feeder opening of 3.2 cm. Feed efficiency did not differ among treatments. In conclusion, ADG, ADFI, HCW, and backfat were increased with the WD feeder evaluated in this experiment, but the growth of pigs fed with a WD feeder was more sensitive to differences in feeder adjustment than that of pigs fed with a CD feeder.

Key words: dry feeder, feeder adjustment, feeder design, finishing pigs, wet–dry feeder

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INTRODUCTION

Previous research has demonstrated that a wet–dry (**WD**) feeder can increase the ADG and ADFI of finishing pigs compared with a conventional dry (**CD**) feeder, (Brumm et al., 2000; Gonyou and Lou, 2000), but differences in G:F of pigs fed with dry and WD feeders have not been consistent. Differences in pig performance might also be influenced by feeder adjustment (Smith et al., 2004; Duttlinger, et al. 2009) because this affects the ease or difficulty with which pigs are able to access feed from a feeder and their feeding behaviors, which could affect ADFI, ADG, G:F, and carcass backfat depth (Braude et al., 1959; Barber et al., 1972; Kanis, 1988). Differences in the amount of feed wasted can result from differences in feeder design, but decreases in ADFI and G:F can occur when pigs require more effort to obtain feed (Morrow and Walker, 1994a; Gonyou, 1998).

Relatively little information is available to assist producers in determining the optimal adjustment

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of feeders with ad libitum feeding. Smith et al. in the nursery (2004) and Duttlinger et al. (2009) working with finisher pigs reported that a multiple-space, CD feeder should be adjusted to provide feed covering approximately 40 to 75% and 61% of the bottom of the feed trough during nursery and finisher stages, respectively. Whether similar recommendations are appropriate for a WD feeder has not been determined; therefore, we conducted 2 experiments to evaluate the effects of feeder adjustment with both a WD feeder and a CD feeder on the performance and carcass characteristics of growing–finishing pigs. Because different dietary ingredients affect feeder adjustment, a third experiment was conducted using 2 diet compositions to determine whether changing adjustment of the WD feeder during growing–finishing would improve G:F and decrease backfat with a sustained improvement in ADG compared with pigs fed with a CD feeder.

MATERIALS AND METHODS

Animal Care and Housing

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The research was conducted in a commercial finishing research facility in southwestern Minnesota. The facility was double-curtain-sided with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 3.0 by 5.5 m.

Feeder Description

Half the pens were equipped with a single-sided, 152.4-cm hole, stainless steel dry feeder (Figure 1; STACO, Inc., Schaefferstown, PA). The feeder was divided into 5 feeding spaces using metal rods and each measured 30.8 cm in width. The depth of the feeding space as measured from the top front of the feeding pan lip to the feed access agitation plate was 20 cm at the bottom of the feeding pan was 17 cm. The feed access agitation plate was designed so that it could be moved up and down by the pigs at any particular feeder setting, and provided for a range of opening size (approximately 0.72 cm) for pigs to access feed. The height of the front of the feeding pan lip was 12.7 cm as measured perpendicular from the bottom of the feeding pan to the top of the lip. Water source was provided by 1-cup waterer in each pen containing the dry feeder located midway between the alley and the dry feeder (Figure 1).

The remaining pens were each equipped with a double-sided, stainless steel, single-space WD feeder (Figure 2; Crystal Springs, GroMaster, Inc., Omaha, NE). The feeding space width was 38.1 cm on both sides to provide

Figure 1. Conventional dry feeder with cup waterer. See online version for figure in color.

access to feed and water. Water was supplied from a single-nipple waterer located under a feed shelf located over the center of the feed pan. The feed shelf was 3.8 cm wide and located 24.8 cm above the bottom of the feed space. An adjustable metal plate was used to regulate the width of the opening for feed access. The distance from the feed shelf to the bottom of the metal plate was used to determine the various feeder adjustment settings for the WD feeders. The depth of the feeding area from the top of the front lip of the feed pan to metal bars guarding water nipple access was 21 and 18.8 cm at the bottom of the feeding pan. Every feeder was positioned perpendicular to the fence line adjacent to pens with a dry feeder.

Although the pens equipped with a WD feeder also contained a cup waterer, these were shut off during the experiments so the only source of water for pigs in these pens was through the WD feeder. This approach was based on the recommendation of the feeder manufacturer. In addition, water was delivered to all the pens of each feeder

Figure 2. Wet–dry feeder. The cup waterer was shut off so the only source of water was through the feeder. See online version for figure in color.

Figure 3. Wet–dry feeder with a 1.27-cm opening (Setting 6) and approximately 35% trough coverage. See online version for figure in color.

Figure 4. Wet–dry feeder with a 1.91-cm opening (Setting 10) and approximately 57% trough coverage. See online version for figure in color.

design independently, and each of the 2 water lines was equipped with a single water meter to monitor total water disappearance for each feeder design.

Experiment 1

A total of 1,296 pigs (PIC 337 × 1050, Hendersonville, TN; initially 19 kg BW) were used in a 27-d experiment to evaluate the effects of feeder design (CD vs. WD feeder) and initial feeder adjustment on grower pig performance. Pigs were placed into pens of 27, with each pen consisting of 14 barrows and 13 gilts. Pigs were visually evaluated for physical defects, and these pigs were excluded from being placed in test pens. Pigs were placed into pens without regard to BW and then sorted to achieve the appropriate gender ratio. Pens of pigs were weighed and allotted to the 2 feeder designs and 3 initial feeder openings within each feeder type in a completely randomized design (CRD) nested within feeder type. There were 24 pens/feeder and 8 pens for each of the 3 feeder openings within each feeder type.

The 3 openings used for the WD feeder were 1.3, 1.9, and 2.5 cm (Figures 3, 4, and 5). For the CD feeder, the agitation plate was designed so that it could be moved up and down by the pigs at any particular feeder setting, and provided for a range of opening size (approximately 0.72 cm) for pigs to access feed. The 3 opening sizes used for the CD feeder were approximately 1.8, 2.4, and 3.1 cm (Figures 6, 7, and 8). Feeder gap openings were left constant throughout the study.

On d 19, measurements of the feeder openings were obtained for all feeders. For the WD feeder, the mean gap opening for each feeder was determined with 2 measurements (one from each side of the feeder) from the top of the feeder shelf to the bottom edge of the feed storage hopper. For the dry feeder, a narrow and wide measurement of the gap opening between the bottom of the feeder trough and bottom edge of the agitation plate was obtained from each end of the feeder; therefore, a mean narrow, mean wide, and mean overall gap opening were determined for each dry feeder. A digital photo of the trough of each feeder also was taken on d 19. Subsequently, the photos were independently scored for percentage of trough coverage by a trained panel of 6 people. The mean trough coverage of each feeder was determined to evaluate the relationship between feeder opening and percentage of feed coverage in the trough.

Pens of pigs were weighed and feed disappearance was measured on d 0, 13, and 27 to determine ADG, ADFI, G:F, and mean BW. All pigs were fed the same corn–soybean [*Zea mays* L. and *Glycine Max* (L.) Merr.] meal diets containing 15% dried distillers grains with solubles (**DDGS**) fed in meal form with a target ground corn particle size mean of 500 to 600 µm (Table 1). The diet was formulated to meet or exceed the nutrient requirement estimates (NRC, 1998).

Experiment 2

A total of 1,248 pigs (PIC 337 × 1050, initially 33 kg BW) was used in a 93-d experiment to evaluate the effects

Figure 5. Wet–dry feeder with a 2.54-cm opening (Setting 14) and approximately 65% trough coverage. See online version for figure in color.

Figure 6. Conventional dry feeder with a 1.49- to 2.04-cm opening (Setting 6) and approximately 9% trough coverage. See online version for figure in color.

Table 1. Diet composition, Exp. 1 and 2, as-fed basis

Item	Dietary phase[1] 23 to 45 kg	45 to 73 kg	73 to 102 kg	102 kg to market
Ingredient, %				
Corn	61.46	66.53	71.45	63.35
Soybean meal, 46.5% CP	21.43	16.64	11.85	19.80
DDGS[2]	15.00	15.00	15.00	15.00
Monocalcium P, 21% P	0.15	–	–	–
Limestone	1.00	0.95	0.90	1.00
Salt	0.35	0.35	0.35	0.35
Liquid lysine, 60%	0.45	0.40	0.35	0.35
L-threonine	0.05	0.03	0.01	0.01
VTM + phytase[3]	0.11	0.10	0.09	0.085
Ractopamine HCl, 20 g/kg[4]	–	–	–	0.025
Total	100.00	100.00	100.00	100.00
Calculated analyses				
Standardized ileal digestible (SID) AA				
Lys, %	1.05	0.90	0.75	0.95
Ile:lys, %	64	66	69	68
Leu:lys, %	158	172	191	170
Met:lys, %	28	30	33	30
Met and Cys:lys, %	57	62	68	61
Thr:lys, %	62	63	64	62
Trp:lys, %	17	17	17	18
Val:lys, %	75	79	84	80
CP, %	19.3	17.5	15.7	18.7
Total lys, %	1.19	1.03	0.87	1.09
ME, kcal/kg	3,358	3,366	3,371	3,364
SID lys:ME, g/Mcal	3.13	2.67	2.23	2.82
Ca, %	0.50	0.44	0.41	0.47
P, %	0.46	0.41	0.39	0.42
Available P, %	0.29	0.25	0.23	0.21

[1]Each dietary phase was formulated to meet the requirements for the BW ranges described in the table.

[2]Dried distillers grains with solubles.

[3]VTM = Vitamin and trace mineral premix. Phytase was estimated to provided 0.12% available P.

[4]Paylean, Elanco Animal Health, Greenfield, IN.

of feeder design (CD vs. WD feeder) and adjustment on growing–finishing pig performance and carcass characteristics. Pigs were placed into pens of 26, with each pen consisting of 13 barrows and 13 gilts. Pens of pigs were weighed and allotted to the 2 feeder types and 3 feeder openings within each feeder type in a CRD nested within feeder type. Pigs were visually evaluated for physical defects, and defective pigs were excluded from the experiment. Pigs were placed into pens without regard to BW and then sorted to achieve the appropriate gender ratio. There were 24 pens/feeder type and 8 pens for each of the 3 feeder openings within each feeder type.

The 3 openings used for the WD feeders were 1.9, 2.5, and 3.2 cm (Figures 4, 5, and 9). The 3 openings used for the dry feeder were approximately 1.8, 2.4, and 3.1 cm. The feeder opening treatments were maintained throughout the experiment.

Figure 7. Conventional dry feeder with a 2.03- to 2.72-cm opening (Setting 8) and approximately 21% trough coverage. See online version for figure in color.

Pens of pigs were weighed and feed disappearance was measured on d 0, 14, 28, 42, 58, 79, and 93 to determine ADG, ADFI, G:F, and mean BW. All pigs were fed the same corn–soybean meal diets used in Exp. 1 during the 4 dietary phases of Exp. 2 (Table 1). Diet phases were fed from d 0 to 14, 14 to 42, 42 to 72, and the final diet containing 5 ppm ractopamine HCl (Paylean, Elanco, Greenfield, IN) was fed from d 72 to 93.

On d 79, 3 pigs (2 barrows and 1 gilt) from each pen were weighed and removed for marketing. These pigs were selected visually within gender as the heaviest pigs in the pen. At the conclusion of the experiment on d 93, the remaining pigs were individually tattooed and shipped approximately 96 km to a commercial processing plant (Swift, Worthington, MN), where they were slaughtered and carcass data were obtained. Carcass data included HCW, carcass yield, and backfat and longissimus muscle depth measurements, which were obtained by using an optical probe (Fat-O-Meater; SFK Technology A/S, Denmark) inserted between the 3rd and 4th rib from the last rib at 7 cm from the dorsal midline. The fat-free lean index (FFLI) was calculated according to NPPC (2000) procedures.

On d 41 and 84, measurements of the feeder opening were obtained for all feeders as in Exp. 1, and a photo of the trough of each feeder was taken. As in Exp. 1, the pictures were scored for percentage of trough coverage so the relationship between feeder opening and feed coverage of the

Figure 8. Conventional dry feeder with a 2.76- to 3.44-cm opening (Setting 10) and approximately 79% trough coverage. See online version for figure in color.

Figure 9. Wet–dry feeder with a 3.18-cm opening (Setting 18) and approximately 84% trough coverage. See online version for figure in color.

Figure 10. Conventional dry feeder with a 2.11- to 2.84-cm opening (Setting 8) and approximately 57% trough coverage. See online version for figure in color.

trough could be determined.

Experiment 3

A total of 1,287 pigs (PIC 337 × 1050, initially 38 kg BW) were used in a 92-d experiment to compare the effects of the CD feeder, 3 WD feeder adjustment strategies, and 2 diet types in a 4 by 2 factorial arrangement of treatments on growing–finishing pig performance and carcass characteristics in a CRD nested within feeder type. Because different ingredients have different flow ability characteristics, we hypothesized that a possible difference in the flow ability of the 2 diet types might interact with the feeder opening. Each pen held 27 pigs (13 or 14 barrows and 13 or 14 gilts) and there were 6 pens for each of the 8 treatments. Pigs were visually evaluated for physical defects, and defective pigs were excluded from being placed in test pens. Pigs were placed into pens without regard to BW and then sorted to achieve the appropriate gender ratio. To obtain an equal number of replications across the 4 feeder treatments, 12 pens were equipped with the CD feeder, and 36 pens were equipped with a WD feeder to evaluate the 3 WD feeder adjustment strategies.

The first WD strategy consisted of maintaining an opening of 3.2 cm throughout the study. The second WD strategy consisted of an initial opening of 3.2 cm until d 56, followed by a decreased opening of 2.5 cm for the remainder of the experiment. The third WD strategy consisted of an initial opening of 3.2 cm until d 28, followed by an opening of 2.5 cm until d 56, and an opening of 1.9 cm for the remainder of the experiment. The CD feeder was maintained at an opening of approximately 2.4 cm throughout the study (Figure 10). Pen and feeder weights were measured on d 14, 28, 42, 56, 72, and 92 to determine ADG, ADFI, G:F, and mean BW.

The 2 diet types evaluated in this study were a corn–soybean meal–15% DDGS diet (**CS**) and a corn–25% DDGS–20% bakery byproduct–soybean meal diet (**BY**). Both diets were fed over 4 dietary phases (Table 2) in meal form with a target ground corn particle size mean of 500 to 600 μm. The 2 diets within each of the 4 feeding phases were formulated to a similar standardized ileal digestible lysine:ME ratio (g/Mcal). Digestibility values for AA were obtained from the NRC (1998) and used for all ingredients except DDGS and bakery byproduct. For DDGS, AA digestibility values from Stein et al. (2006) were used. For the bakery byproduct, the AA digestibility values from the NRC (1998) for soft red winter wheat (*Triticum aestivum* L.) were used. A ME value of 3,420 kcal/kg was used for both corn and DDGS. All dietary nutrient concentrations were formulated to meet or exceed the requirement estimates of pigs for each diet phase (NRC, 1998).

On d 20 and 83, measurements of the feeder opening were obtained for all feeders as in the previous experiments, and a photo of the trough of each feeder was taken and scored as described in Exp. 2. On d 72, 3 pigs (2 barrows and 1 gilt) from each pen were weighed and removed for marketing using similar procedures to Exp. 2. On d 94 (approximately 48 h after collecting the final pen weights), the remaining pigs were individually tattooed and shipped approximately 96 km to a commercial processing plant (Swift, Worthington, MN), where they were slaughtered and carcass data were obtained as described for Exp. 2.

Statistical Analyses

Pen BW gain, feed intake, and pig days were used for the calculation of ADG, ADFI, and G:F. Pigs that died or were removed were weighed and their date of removal recorded, and their BW gain and contributed pig days were used in the calculation of ADG, ADFI, and G:F. Pigs were removed if they had been identified by caretakers and did not show signs of recovery within 48 h after identification.

For both Exp. 1 and Exp. 2, data were analyzed as a CRD using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC) with the 3 feeder openings nested within each of the 2 feeder designs. Linear and quadratic contrasts were used to evaluate the effects of increasing the feeder opening within each feeder design. Pen was the experimental unit. In Exp. 2, HCW was used as a covariate in the analysis of other carcass characteristics.

The data for Exp. 3 were analyzed as a 4 by 2 factorial arrangement of treatments, with 4 feeder treatments

Table 2. Diet composition, Exp. 3, as-fed basis

Item	Dietary phase[1]							
	36 to 59 kg		59 to 84 kg		84 to 107 kg		107 kg to market	
	CS[2]	BY[2]	CS	BY	CS	BY	CS	BY
Ingredient, %								
Corn	65.02	37.31	68.51	40.74	72.14	44.45	63.30	35.62
Soybean meal, 46.5% CP	17.80	15.60	14.60	12.25	11.05	8.60	19.80	17.35
DDGS[3]	15.00	25.00	15.00	25.00	15.00	25.00	15.00	25.00
Bakery byproduct	–	20.00	–	20.00	–	20.00	–	20.00
Monocalcium P, 21% P	0.15	–	–	–	–	–	–	–
Limestone	1.00	1.00	0.95	1.00	0.95	1.00	1.00	1.05
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Lysine sulfate	0.54	0.62	0.48	0.56	0.42	0.51	0.42	0.51
L-threonine	0.03	0.01	0.01	–	–	–	0.01	–
VTM + phytase[4]	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09
Ractopamine HCl, 20 g/kg[5]	–	–	–	–	–	–	0.025	0.025
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analyses								
Standardized ileal digestible (SID) AA								
Lys, %	0.96	0.98	0.85	0.86	0.73	0.74	0.95	0.96
Ile:lys, %	64	66	66	69	69	72	68	70
Leu:lys, %	164	169	176	183	194	201	171	177
Met:lys, %	29	30	31	33	34	36	30	32
Met and cys:lys, %	59	62	63	67	69	74	62	65
Thr:lys, %	60	60	62	62	63	66	62	63
Trp:lys, %	17	17	17	17	17	17	18	18
Val:lys, %	76	79	80	83	85	88	80	83
CP, %	17.9	19.4	17.1	18.5	15.7	17.1	19.0	20.4
Total lys, %	1.10	1.13	0.98	1.01	0.85	0.88	1.09	1.12
ME, kcal/kg	3,360	3,422	3,371	3,428	3,373	3,428	3,366	3,424
SID lys:ME, g/Mcal	2.86	2.86	2.52	2.52	2.16	2.17	2.82	2.81
Ca, %	0.49	0.48	0.44	0.47	0.42	0.46	0.47	0.50
P, %	0.44	0.44	0.40	0.43	0.39	0.41	0.42	0.45
Available P, %	0.28	0.29	0.25	0.26	0.23	0.25	0.21	0.26

[1]Each dietary phase was formulated to meet the requirements for the BW ranges described in the table.

[2]CS = Corn-soybean meal-15% dried distillers grains with solubles (DDGS); BY = Corn-DDGS-bakery byproduct-soybean meal.

[3]Dried distillers grains with solubles.

[4]VTM = Vitamin and trace mineral premix. Phytase was estimated to provide 0.07 to 0.12% available P.

[5]Paylean, Elanco Animal Health, Greenfield, IN.

(1 dry feeder and 3 WD feeder adjustment strategies) and the 2 diet types in a CRD using the PROC MIXED procedure. Preplanned orthogonal contrasts were used to compare the overall effects of feeder design, as well as to compare feeder adjustment strategies among pigs fed with the WD feeder. Pen was the experimental unit, and HCW was used as a covariate in the analysis of other carcass characteristics. For all analyses, differences with a *P*-value of less than 0.05 were considered significant.

RESULTS

Experiment 1

The mean opening of the CD feeder was greater ($P < 0.001$) than that of the WD feeder on d 19 (Table 3); however, the percentage of trough coverage of the CD feeder was less ($P < 0.001$) than that of the WD feeder. The openings of both feeder designs increased (linear, $P < 0.001$) with greater feeder adjustment setting. The openings achieved were 1.49 to 2.04, 2.03 to 2.72, and 2.76 to 3.44 cm for the CD feeder, and 1.27, 1.91, and 2.54 cm for the WD feeder. The percentage of trough coverage of the CD feeder increased (quadratic, $P < 0.01$) with greater feeder opening, as did that of the WD feeder (linear, $P < 0.001$).

From d 0 to 27, pigs fed with the WD feeder had decreased ($P < 0.02$) ADFI and better G:F compared with pigs fed with the CD feeder. Increased feeder opening of the WD feeder increased (quadratic, $P < 0.02$) ADG, ADFI, and d-27 BW. Increased feeder opening of the CD feeder also increased (linear, $P < 0.01$) ADFI. There

Table 3. Effects of feeder design and initial feeder setting on the trough coverage and growth performance of grower pigs, Exp. 1

	Initial feeder opening, cm							P <				
	Wet–dry feeder design			Conventional dry feeder design					Wet–dry		Conventional dry	
Item	1.3	1.9	2.5	~1.8	~2.4	~3.1	SEM	Feeder type	Linear	Quadratic	Linear	Quadratic
Feeder data, d 19[1]												
Maximum opening[2], cm	1.27	1.91	2.54	2.04	2.72	3.44	0.058	0.001	0.001	1.000	0.001	0.754
Minimum opening[3], cm	1.27	1.91	2.54	1.49	2.03	2.76	0.068	0.010	0.001	1.000	0.001	0.243
Avg. opening, cm	1.27	1.91	2.54	1.77	2.37	3.10	0.061	0.001	0.001	1.000	0.001	0.435
Trough coverage, %	34.9	57.3	64.5	9.0	21.1	79.0	5.70	0.010	0.001	0.285	0.001	0.002
Live performance												
d 0 to 27												
ADG, kg	0.59	0.71	0.75	0.66	0.68	0.69	0.012	0.859	0.001	0.010	0.191	0.557
ADFI, kg	1.07	1.28	1.34	1.22	1.26	1.30	0.016	0.020	0.001	0.001	0.001	0.873
G:F	0.55	0.55	0.56	0.54	0.54	0.53	0.006	0.010	0.132	0.820	0.110	0.469
d 27 BW, kg	35.2	38.5	39.7	37.3	37.8	38.1	0.33	0.849	0.001	0.020	0.097	0.902

[1]1,296 pigs with an initial BW of 19.4 kg were placed in 48 pens containing 27 pigs each.

[2]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) or feeder hopper (wet–dry) at the narrowest position.

[3]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) or feeder hopper (wet–dry) at the widest position.

was no evidence that removal rates differed among treatments ($P = 0.23$; data not shown).

Experiment 2

The mean openings of the CD feeder and WD feeder were the same on d 41 and 84 for each feeder setting (2.5 cm). The openings of both feeder types increased (Table 4; linear, $P < 0.001$) with greater feeder adjustment setting. The openings achieved were 1.47 to 2.08, 2.11 to 2.84, and 2.80 to 3.45 cm for the CD feeder, and 1.91, 2.54, and 3.18 cm for the WD feeder. The percentage of trough coverage for both feeder types increased (linear, $P < 0.001$), with greater feeder opening on both d 41 and 84. The percentage of trough coverage of the CD feeder was less ($P < 0.02$) than that of the WD feeder on d 41, but they did not differ on d 84.

Overall (d 0 to 93), pigs fed with the WD feeder had increased ($P < 0.05$) ADG, ADFI, final BW, HCW, and backfat depth, but decreased ($P < 0.001$) FFLI compared with pigs fed with the CD feeder. Neither feeder type nor opening influenced overall G:F. Increased feeder opening of the WD feeder also resulted in increased (linear, $P < 0.05$) ADG, ADFI, final BW, HCW, and backfat depth, but decreased ($P < 0.02$) FFLI; however, increasing the feeder opening of the CD feeder had no effect on growth performance and carcass characteristics. There was no evidence that removal rates differed among treatments ($P = 0.36$; data not shown).

Experiment 3

The mean opening of the WD feeder was greater ($P < 0.001$) than that of the CD feeder on d 20 and 83, but the mean opening of the CD feeder was greater ($P < 0.05$) on d 83 than that of the WD feeder with a decreased opening of 1.9 cm (Table 5). The mean opening of the WD feeder decreased ($P < 0.05$) with each decrease in the mechanical setting, from 3.2 to 2.5 to 1.9 cm. A feeder design × diet type interaction ($P < 0.01$) was observed for the percentage of trough coverage on d 20. This result occurred because trough coverage of the WD feeder was relatively similar between the 2 diet types, but trough coverage of the CD feeder was considerably greater with the BY diet than with the CS diet. No differences occurred in trough coverage on d 83, but trough coverage for the WD feeder with an opening of 1.9 cm and the CD feeder were numerically least among the treatments.

No feeder × diet type interactions were observed for growth and carcass characteristics during the experiment. Overall growth performance and carcass characteristics of pigs fed the 2 diet types did not differ (data not shown). From d 0 to 28, pigs fed with the WD feeder had greater ($P < 0.02$) ADG and ADFI than pigs fed with the CD feeder (Table 6); however, no differences were noted among treatments in G:F or d-28 BW.

From d 28 to 56, all pigs fed using the WD feeder continued to have greater ($P < 0.001$) ADG and ADFI than pigs fed using the CD feeder, and the performance of pigs fed with a WD feeder at a decreased opening of 2.5 cm remained similar to that of pigs fed with a WD feeder opening of 3.2 cm. This resulted in a heavier ($P < 0.002$) d-56 BW for pigs fed with the WD feeder than for pigs fed using the CD feeder. No differences were detected in G:F among feeder treatments.

From d 56 to 92 and overall (d 0 to 92), all pigs fed using the WD feeder had greater ($P < 0.001$) ADG, ADFI, and final BW than pigs fed with the CD feeder; however,

Table 4. Effects of feeder design and feeder setting on the trough coverage, growth performance, and carcass characteristics of growing–finishing pigs, Exp. 2

	Initial feeder opening, cm							$P <$				
	Wet–dry feeder design			Conventional dry feeder design					Wet–dry		Conventional dry	
Item	1.9	2.5	3.2	~1.8	~2.4	~3.1	SEM	Feeder type	Linear	Quadratic	Linear	Quadratic
Feeder data[1]												
Maximum opening[2], cm	1.91	2.54	3.18	2.08	2.84	3.45	0.058	0.001	0.001	1.000	0.001	0.289
Minimum opening[3], cm	1.91	2.54	3.18	1.47	2.11	2.80	0.068	0.001	0.001	1.000	0.001	0.778
Avg. opening, cm	1.91	2.54	3.18	1.78	2.47	3.13	0.059	0.107	0.001	1.000	0.001	0.793
d 41 trough coverage, %	52.5	63.1	84.9	23.6	58.4	83.0	5.85	0.017	0.001	0.442	0.001	0.484
d 84 trough coverage, %	52.9	72.0	82.3	40.4	66.3	83.0	5.87	0.205	0.001	0.520	0.001	0.501
Live performance, d 0 to 93												
ADG, kg	0.94	0.97	1.01	0.89	0.92	0.92	0.017	0.001	0.006	0.974	0.189	0.336
ADFI, kg	2.51	2.64	2.77	2.38	2.45	2.42	0.067	0.001	0.006	0.988	0.622	0.485
G:F	0.38	0.37	0.36	0.37	0.38	0.38	0.008	0.273	0.281	0.981	0.483	0.947
Final BW, kg	119.3	121.8	126.1	114.5	117.7	117.8	2.51	0.005	0.048	0.761	0.329	0.597
Carcass characteristics[4]												
HCW, kg	87.2	89.8	92.7	85.5	87.3	87.8	1.80	0.040	0.034	0.932	0.349	0.764
Backfat depth, mm	16.9	17.1	18.3	16.5	16.3	16.2	0.38	0.001	0.018	0.231	0.603	0.905
Loin depth, cm	6.18	6.16	6.09	6.13	6.11	6.03	0.135	0.003	0.622	0.891	0.526	0.833
FFLI[5]	50.2	50.1	49.5	50.4	50.5	50.5	0.19	0.001	0.012	0.235	0.619	0.989

[1]1,248 pigs with an initial BW of 33.1 kg were placed in 48 pens containing 26 pigs each.

[2]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) or feeder hopper (wet–dry) at the narrowest position.

[3]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) or feeder hopper (wet–dry) at the widest position.

[4]1,021 pigs were used to determine the carcass characteristics of the feeder treatments. Hot carcass weight was used as a covariate in the analysis of other carcass characteristics. Carcass data means do not include data from the 3 pigs per pen removed on d 79; however, their data were used in the calculation of the live performance results.

[5]FFLI = fat-free lean index.

within the WD feeder treatments, pigs fed using a WD feeder with the opening decreased to 2.5 and 1.9 cm had decreased ($P < 0.05$) ADG compared with pigs using the WD feeder with an opening maintained at 3.2 cm. In addition, pigs fed using a WD feeder with the opening decreased to 1.9 cm had a lower ($P < 0.05$) ADFI than pigs fed with the WD feeder maintained at an opening of 3.2 cm. The ADFI by pigs fed using a WD feeder with the opening decreased to 2.5 cm was intermediate. No differences were found in G:F among feeder treatments, and there was no evidence that removal rates differed among treatments ($P = 0.46$; data not shown).

Pigs fed using the WD feeder had greater ($P < 0.02$) HCW, carcass yield, and backfat depth than pigs fed with the CD feeder, but loin depth of pigs fed with the WD feeder was less ($P < 0.04$) than that of pigs fed with the dry feeder. The differences in backfat and loin depth resulted in pigs fed with the WD feeder having lower ($P < 0.001$) FFLI than pigs fed with the dry feeder; however, within the WD feeder treatments, pigs fed with a feeder opening decreased to 1.9 cm had decreased ($P < 0.05$) backfat depth and increased ($P < 0.05$) FFLI compared with those fed with a feeder opening maintained at 3.2 cm. The backfat depth and FFLI of pigs fed using the WD feeder with a final opening of 2.5 cm were intermediate among treatments.

DISCUSSION

As demonstrated in previous studies with growing–finishing pigs fed meal diets ad libitum, ADG, ADFI, and final BW were generally improved for pigs fed with a WD feeder (Brumm et al., 2000; Gonyou and Lou, 2000); however, the magnitude of differences in ADG and final BW (compared to a dry feeder) within various studies seems to depend on the differences in ADFI and G:F. These differences can be influenced by other feeder design features (Baxter, 1991; Lou and Gonyou, 1997), the number of pigs per feeder space (Walker, 1990; Morrow and Walker, 1994b), and the association of these variables with feeding behavior (Hyun et al., 1997; Gonyou and Lou, 2000). In contrast to growing–finishing pigs, pigs fed with a WD feeder during the nursery phase had similar growth rate but poorer feed efficiency compared with those fed with a multi-space dry feeder (O'Connell et al., 2002).

The current studies were performed specifically to evaluate the effects of different feeder openings (settings) of the dry and WD feeder design on the performance and carcass characteristics of pigs in a commercial research barn. The mechanical adjustment of the feeder opening is the only feature of a feeder that can be readily changed by barn staff. Presumably, the feeder opening is designed to be adjustable so it can accommodate differences in the flow characteristics of feeds and provide unrestricted ac-

Table 5. Effect of feeder design, diet type, and changing the feeder setting of a wet–dry feeder on feeder gap opening and trough coverage during the growing–finishing period, Exp. 3

	Feeder opening, cm												
	Wet–dry[1]						Conventional dry[1]						
	3.2		3.2–2.5		3.2–2.5–1.9		~2.4			*P* <			
Item	CS[2]	BY	CS	BY	CS	BY	CS	BY	SEM	Feeder design × diet type	Feeder design	Diet type	Wet–dry opening
Feeder data	3.2 cm		2.5 cm		1.9 cm								
Maximum opening, cm[3,4]	3.18^{a}		2.54^{b}		1.91^{c}		2.71^{d}		0.070	NA[5]	0.001	NA	0.001
Minimum opening, cm[6]	3.18^{a}		2.54^{b}		1.91^{c}		1.88^{c}		0.085	NA	0.001	NA	0.001
Avg. opening, cm	3.18^{a}		2.54^{b}		1.91^{c}		2.30^{d}		0.076	NA	0.001	NA	0.001
d 20 trough coverage, %	73	80	NA	NA	NA	NA	41	86	7.0	0.01	0.060	0.001	NA
d 83 trough coverage, %	76	89	78	84	64	62	58	69	10.1	0.555	0.071	0.234	0.084

[1]24 pens containing 27 pigs each was used, with 6 pens containing the conventional dry feeder and 18 pens containing the wet–dry feeder.

[2]Diet type: CS = corn–soybean meal–15% dried distillers grains with solubles (DDGS); BY = corn–soybean meal–25% DDGS–20% bakery byproduct.

[3]Means within a row with different superscripts differ, $P < 0.05$.

[4]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) at the narrowest position or feeder hopper (wet–dry).

[5]NA = not applicable.

[6]Measured from the bottom of the feed pan (dry) or shelf (wet–dry) to the bottom of the feed agitation plate (dry) at the widest position or feeder hopper (wet–dry).

cess to feed with little waste, but despite an emphasis on feeder adjustment to obtain the best possible feed efficiency, relatively little data are available to establish recommendations for an ideal feeder adjustment.

Because feeder adjustment is one of the few feeding management practices under direct control of barn staff, feeder pan coverage is a common subjective method for evaluating appropriate feeder adjustment under field conditions. Therefore, in our studies we evaluated feeder pan coverage to provide a practical interpretation of the gap width settings used in our studies. We should note, however, that similar to the depictions in the figures, this subjective evaluation of feeder pan coverage is more difficult with the wet dry feeder.

The settings evaluated for the CD feeder in Exp. 1 and 2 were selected to validate results previously using the same dry feeders obtained at the same facility by Duttlinger et al. (2009), but for lighter pigs (Exp. 1) and for a longer duration (Exp. 2). After 2 experiments, Duttlinger et al. (2009) concluded that the ideal feeder setting provided feed covering slightly more than half the bottom of the feed trough, regardless of diet type. In their experiments, the difference in ADG between a trough coverage of 45 to 70% and a trough coverage of >70% were minimal, and ADFI was the only criterion that increased consistently with each increase of the feeder opening in both experiments. Feed efficiency was numerically the best with a trough coverage of 45 to 70% in their experiments, with slightly lower G:F at a trough coverage < 45% and >70%, corresponding to a 2.0- to 2.9-cm opening.

Myers et al. (2011) compared 3 feeder settings with a dry feeder, which were obtained by adjusting the feeder agitation plate to a minimum opening of 1.27, 1.91, or 2.54 cm. Similar to the dry feeder used in the current studies, the agitation plate was designed so it could be moved precisely 0.64 cm upward, which provided a range of openings for pigs to access feed. These authors reported ADG and ADFI responses similar to those observed by Duttlinger et al. (2009), but G:F was greatest at the lowest opening (1.27 to 1.91 cm). Based on numerically greater ADG from d 0 to 28 (41 to 68 kg) and increased G:F from d 28 to 89 (68 to 128 kg), they suggested that the optimal feeder opening might change during the finisher phase. Myers et al. (2011) indicated that a trough coverage of approximately 58% (1.91- to 2.54-cm opening) for pigs up to 68 kg, followed by a decreased trough coverage of approximately 28% (1.27- to 1.91-cm opening), might provide the best overall performance; however, they used a dry feeder with 2 feeding spaces and 3 or 4 pigs per feeder space (approximately 8.9-cm linear trough space/pig). In another experiment, Myers et al. (2010) compared a narrow feeder opening (1.27 to 1.91 cm) to a wide opening (2.54- to 3.18-cm opening) at 2 trough densities (4.4-cm vs. 8.9-cm linear trough space/pig) from 37 kg to 129 kg BW. Although ADG did not differ, pigs fed at the narrow opening had decreased ADFI and increased G:F. The narrow opening was associated with 42.9% trough coverage at the greater trough density and 54.1% trough coverage at the lower trough density compared with corresponding trough coverage of 83.3% and 86.5% at the wide opening.

Similar to the results of previous experiments, an increased feeder opening of the CD feeder in Exp. 1 and 2 did not result in appreciable differences in the ADG by growing–finishing pigs. Collectively, however, these experiments imply that trough coverage of approximately

Table 6. Effects of feeder design and changing the feeder setting of a wet–dry feeder on the growth performance and carcass characteristics of growing–finishing pigs, Exp. 3[1]

	Feeder opening, cm						
	Wet–dry			Dry		$P <$	
Item	3.2	3.2–2.5	3.2–2.5–1.9	~2.4	SEM	Feeder design	Wet–dry setting
Live performance							
d 0 to 28, feeder opening, cm	3.2	3.2	3.2	~2.4			
ADG, kg	0.97	0.95	0.95	0.90	0.012	0.001	N/A[3]
ADFI, kg	2.12	2.13	2.13	2.06	0.025	0.015	N/A
G:F	0.45	0.44	0.45	0.44	0.004	0.071	N/A
d 28 BW, kg	64.5	63.8	64.3	62.9	0.93	0.218	N/A
d 28 to 56, feeder opening, cm	3.2	3.2	2.5	~2.4			
ADG, kg	0.99	0.98	0.99	0.89	0.011	0.001	0.842
ADFI, kg	2.89	2.84	2.83	2.56	0.033	0.001	0.454
G:F	0.34	0.35	0.35	0.35	0.003	0.894	0.227
d 56 BW, kg	92.4	91.3	92.1	87.7	1.07	0.002	0.815
d 56 to 92, feeder opening, cm	3.2	2.5	1.9	~2.4			
ADG[4], kg	1.15[a]	1.10[b]	1.08[b]	1.04[c]	0.014	0.001	0.007
ADFI, kg	3.27[a]	3.16[ab]	3.05[b]	2.93[c]	0.039	0.001	0.001
G:F	0.35	0.35	0.36	0.35	0.003	0.568	0.268
Overall (d 0 to 92)							
ADG, kg	1.04[a]	1.01[b]	1.01[b]	0.95[c]	0.008	0.001	0.070
ADFI, kg	2.79[a]	2.74[ab]	2.70[b]	2.54[c]	0.028	0.001	0.036
G:F	0.37	0.37	0.38	0.37	0.003	0.946	0.294
Final BW, kg	132.5[a]	129.1[a]	129.8[a]	123.4[b]	1.25	0.001	0.324
Carcass characteristics[5]							
HCW, kg	95.1[a]	93.2[a]	94.2[a]	89.9[b]	1.11	0.001	0.791
Backfat depth, mm	19.5[a]	19.2[ab]	18.6[b]	17.6[c]	0.30	0.001	0.018
Loin depth, cm	6.32[ab]	6.27[a]	6.35[ab]	6.54[b]	0.085	0.033	0.711
FFLI[6]	49.3[a]	49.4[ab]	49.7[b]	50.2[c]	0.14	0.001	0.017

[1]1,287 pigs with an initial BW of 37.5 kg were placed in 48 pens containing 27 pigs each.

[2]The first wet–dry strategy consisted of maintaining an opening of 3.2 cm throughout the study. The second wet–dry strategy consisted of an initial opening of 3.2 cm until d 56, followed by a reduced opening of 2.5 cm for the remainder of the experiment. The third wet–dry strategy consisted of an initial opening of 3.2 cm until d 28, followed by an opening of 2.5 cm until d 56, and an opening of 1.9 cm for the remainder of the experiment. The conventional dry feeder was maintained at an opening of approximately 2.4 cm throughout the study.

[3]N/A = not applicable.

[4]Means within a row with different superscripts differ, $P < 0.05$.

[5]On d 94, carcass data were obtained for 1,097 pigs. Hot carcass weight was used as a covariate for comparison of backfat depth, loin depth, and FFLI. Because of differences in feed storage capacity between the 2 feeder designs, feed was withheld after the final live BW was obtained for approximately 27 h before slaughter for pigs fed with the wet–dry feeder and 15 h before slaughter for pigs fed with the conventional dry feeder.

[6]FFLI = fat-free lean index.

30 to 50% for pigs > 70 kg and 50 to 70% for pigs < 70 kg will provide sufficient access to feed for growth with a dry self-feeder, but that exceeding this range could result in decreased G:F. Therefore, an opening of 1.9 to 2.7 cm was used for the CD feeder in Exp. 3, which served as a control treatment for the evaluation of WD feeder management strategies.

Present results demonstrate a contrast in the response to different feeder openings with the CD and WD feeder. In both Exp. 1 and 2, increasing the opening of the WD feeder resulted in greater ADG, ADFI, and final BW. Increasing the feeder opening of the dry feeder failed to improve ADFI and ADG to that obtained with the WD feeder at increased openings, which implies that the presentation of feed and water together might be required for any further increase in ADFI and ADG, and that decreased settings of the WD feeder successfully limited the accessibility of feed and decreased ADFI and ADG. The increased sensitivity of WD feeder adjustment along with the greater difficulty in subjectively measuring feeder pan coverage suggests that under field conditions more time by staff may be needed for feeder adjustment with the WD feeders compared to the dry feeders evaluated in this study.

The manner in which pigs were able to obtain access to feed from each of the feeder designs also might have caused differences in the sensitivity of pig performance to the feeder openings. With the CD feeder design, each feeder setting provided a range of openings with a hanging, stainless steel agitation plate that pigs could manipulate to access feed. The WD feeder design used an adjustable feed shelf located above the feed trough, and each feeder setting provided a precise, fixed opening from which feed could be accessible. From a practical standpoint, characterization of the optimal fixed opening width could be a useful monitoring tool for feeder adjustment strategy for the WD feeders evaluated in this study.

In Exp. 1, pigs fed using the WD feeder at the lowest opening (1.27 cm) from d 0 to 27 had decreased ADG and ADFI. This result was potentially associated with the observation that the feeder opening for this feeder treatment was frequently plugged during the first 10 d of the experiment, but this problem abated by the time trough coverage was evaluated on d 19. The ADG and ADFI by pigs using the WD feeder at the 1.91-cm and 2.54-cm openings were only slightly greater than pigs fed with the dry feeder, but G:F was increased. As a result, when all pigs fed with the WD feeder were compared with those fed with the dry feeder, ADG did not differ, ADFI was decreased, and G:F was increased for pigs fed with the WD feeder. In an earlier experiment initiated at a heavier BW (initially 32 kg BW; Bergstrom, 2011), pigs fed with the WD feeder (3.18-cm opening) had slightly greater ADG, similar ADFI, and a tendency toward greater G:F during the first 2 wk compared with those using the CD feeder. Similar to the results of other studies, the magnitude of differences in ADG and ADFI between the WD and dry feeder were greater during later periods of growth. Differences (or changes) in feeding behavior, such as a faster eating rate and decreased time budget for feeding, might be responsible for the increased G:F in the early growing–finishing period when pigs were placed on the WD feeder (Gonyou and Lou, 2000; Bergstrom, 2011). The numeric improvements in overall G:F that were associated with a decreased WD feeder opening in Exp. 2 and 3 indicate that this type of feeder management strategy might be particularly important during the late finishing stages. Moreover, this finding suggests the optimal strategy of changing the feeder gap width for the WD feeder used in this experiment could be different depending on the BW of the pig.

Differences in the backfat depth and FFLI of pigs fed with the WD feeder and dry feeder also are consistent with the findings of earlier research. The linear decrease in backfat depth and a concomitant increase in FFLI observed with decreased WD feeder openings indicates that the differences observed between pigs using the 2 feeder designs are related to differences in ADG and ADFI (Braude et al., 1959; Barber et al., 1972; Kanis, 1988). Although the backfat depth and FFLI of pigs fed using a decreased WD feeder opening in Exp. 2 and 3 were still less than those obtained with the dry feeder, these data demonstrate that feeder management strategies can be used with ad libitum feeding to manipulate the growth and carcass characteristics of growing–finishing pigs fed with the WD feeder.

In Exp. 3 there were differences in the amount of time feed was withheld before their arrival at the processor for slaughter, which occurred after weighing pigs at the farm. The WD feeder had substantially less feed storage capacity (approximately 134 kg less) than the CD feeder. Although the withholding of feed was preplanned to decrease unnecessary feed wastage, differences in feeder capacity and inherent differences in ADFI were not fully accounted for. Pigs fed with the WD feeder were estimated to have been withheld from feed for approximately 27 h before slaughter, whereas pigs fed with the dry feeder were withheld from feed for approximately 15 h before slaughter.

In conclusion, pigs fed with a WD feeder used in this experiment had greater ADG, ADFI, final BW, HCW, and backfat, but decreased FFLI compared with pigs fed with a CD feeder. Although lighter BW pigs in Exp. 1 had increased G:F with a WD feeder, the G:F did not differ when the initial BW was >33 kg. Using different feeder openings for the CD feeder did not result in appreciable differences in overall growth performance or carcass characteristics. In contrast to the results obtained with the dry feeder, the growth performance and carcass characteristics of pigs fed with a WD feeder were significantly influenced by differences in the feeder opening. An increased feeder opening on the WD feeder resulted in further increases in ADG, ADFI, final BW, HCW, and backfat, but decreased FFLI in Exp. 2. Staged decreases in the WD feeder opening during growth resulted in a final BW similar to that obtained when the WD feeder remained at a constant opening, but the overall feed intake was decreased and carcass characteristics improved. Therefore, a staged decrease in feeder opening might be a means to decrease the negative effect of WD feeders on backfat without decreasing growth rate. Nonetheless, as a result of the modest decreases in backfat depth and sensitivity of growth rate to feeder opening, caution should be used when employing this strategy under practical field conditions.

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