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Effects of dietary wheat middlings, corn dried distillers grains with solubles, and net energy formulation on nursery pig performance[1]

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ABSTRACT: Four experiments were conducted to examine effects of dietary wheat middlings (midds), corn dried distillers grains with solubles (DDGS), and NE formulation on nursery pig performance and caloric efficiency. In Exp. 1, 180 nursery pigs (11.86 ± 0.02 kg BW and 39 d of age) were fed 1 of 5 diets for 21 d, with 6 pigs per pen and 6 replications per treatment. Diets were corn–soybean meal based and included 0, 5, 10, 15, or 20% wheat midds. Increasing wheat midds decreased (linear; $P < 0.05$) ADG and ADFI. Caloric efficiency improved (linear; $P < 0.05$) on both an ME (NRC, 1998) and NE (Sauvant et al., 2004) basis as dietary wheat midds increased. In Exp. 2, 210 pigs (6.85 ± 0.01 kg BW and 26 d of age) were fed 1 of 5 diets for 35 d, with 7 pigs per pen and 6 replications per treatment. Diets were corn–soybean meal based and contained 0, 5, 10, 15, or 20% wheat midds. Increasing wheat midds did not affect overall ADG or ADFI but decreased (quadratic; $P < 0.013$) G:F at 20%. Caloric efficiency for both ME and NE improved (quadratic; $P < 0.05$) as dietary wheat midds increased. In Exp. 3, 180 pigs (12.18 ± 0.4 kg BW and 39 d of age) were fed 1 of 6 experimental diets arranged in a 2 × 3 factorial with main effects of DDGS (0 or 20%) and wheat midds (0, 10, or 20%) for 21 d, with 6 pigs per pen and 5 replications per treatment. No DDGS × wheat midds interactions were observed, and DDGS did not influence ADG, ADFI, or G:F, but increasing dietary wheat midds decreased (linear; $P < 0.05$) ADG, G:F, and final BW. In Exp. 4, 210 pigs (6.87 kg BW and 26 d of age) were allotted to 1 of 5 dietary treatments, with 7 pigs per pen and 6 replications per treatment. Wheat middlings (0, 10, or 20%) were added to the first 3 diets without balancing for energy. In diets 4 and 5, soybean oil was added (1.4 and 2.8%) to 10 and 20% wheat midds diets to balance to the same NE as the positive control (0% wheat midds). Overall, no wheat midds × fat interactions occurred. Regardless of formulated energy value, caloric efficiency and G:F were poorer ($P < 0.05$) on an ME basis as wheat midds increased from 10 to 20% of the diet but did not change when calculated on an NE basis. Results of these experiments indicate that wheat midds may be fed up to 10 to 15% of the diet without negatively affecting nursery pig performance and with no interactive effects when fed in combination with DDGS. Also, formulating on an NE basis provided for similar performance with increasing dietary wheat midds compared with a corn–soybean meal control diet.

Key words: caloric efficiency, corn dried distillers grains with solubles, growth, net energy, nursery pigs, wheat middlings

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INTRODUCTION

Wheat middlings (**midds**) are a byproduct of the flour milling industry and are a high-fiber ingredient (crude fiber [**CF**] < 9.5%). Wheat middlings consist of wheat bran, wheat shorts, wheat germ, wheat flour, and some offal from the wheat milling process (Blasi et al., 1998). Although wheat midds have been used mainly in ruminant diets, their use in swine diets has steadily increased because of the high costs of traditional ingredients. Salyer et al. (2012) and Asmus et al. (2012) conducted experiments examining dietary wheat midds for finishing pigs. They concluded that dietary wheat midds decreased both ADG and G:F, which can be explained by the lower energy content of wheat midds compared with corn (3,025 vs. 3,420 kcal/kg of ME, respectively; NRC, 1998). The researchers also

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observed that added wheat midds led to a decrease in diet bulk density and diet energy as well as an increase in NDF content. Although studies have been conducted to study the effects of wheat midds on finishing pig performance, little work has been done to determine the effects of dietary wheat midds on nursery pig performance.

Corn dried distillers grains with solubles (**DDGS**) have become a common ingredient in swine diets (Stein and Shurson, 2009). Corn DDGS and wheat midds are similar in that they are byproduct ingredients with a high CF content (7.3 and 7% respectively). Few data are available on the interactive effects of wheat midds and DDGS in nursery diets as well as the effect of NE formulation of diets containing wheat midds. Therefore, the objectives of these experiments were to determine the effects of 1) increasing dietary wheat midds, 2) potential interactive effects of wheat midds and DDGS, and 3) diet formulation on an NE basis on nursery pig performance and caloric efficiency.

MATERIALS AND METHODS

All practices and procedures used in these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. All 4 experiments were conducted at the Kansas State University Swine Teaching and Research Center in Manhattan, KS. For all 4 experiments, pigs were from a similar genetic line (327 × 1050; PIC, Hendersonville, TN). Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. Pens had wire-mesh floors. All pigs were weaned at approximately 21 d of age and fed common starter diet or diets before implementation of experimental diets. The common diets did not contain wheat midds or DDGS. All diets were prepared at the Kansas State University Animal Sciences and Industry Feed Mill and were fed in meal form.

For experiments 1, 2, and 3, diets were not balanced for energy, so as the level of wheat midds increased, dietary energy decreased. Diets within phase for all experiments were formulated to a constant standard ileal digestible Lys concentration based on the value of the control diet to ensure that changes in performance were due to the addition of wheat midds rather than AA concentrations. For diet formulation, the assumed ME and NE values of DDGS were similar to that of corn (3,420 and 2,650 kcal/kg; NRC, 1998, and Sauvant et al., 2004), and the ME and NE values of wheat midds were 3,025 and 1,850 kcal/kg (NRC, 1998, and Sauvant et al., 2004), respectively. Caloric efficiencies of pigs were determined using dietary ingredient values for ME (DDGS value used was equal to corn) from NRC (1998) and for NE from INRA (Sauvant et al., 2004). Values from NRC (1998) were used instead of NRC (2012) values because the later had not been published at the time of formulation. Caloric efficiencies were calculated on a pen basis by multiplying total pen feed intake by the dietary energy concentration (kcal/kg) and dividing by total pen gain.

Chemical Analysis

Ingredients and samples of each diet were collected from feeders between each weigh day, blended, subsampled, and analyzed at Ward Laboratories, Inc. (Kearney, NE) for DM (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), crude fat (method 920.39 A; AOAC, 2006), CF (method 978.10; AOAC, 2006), ash (method 942.05; AOAC, 2006), Ca (method 965.14/985.01; AOAC, 2006.), P (method 965.17/985.01; AOAC, 2006), ADF (ANKOM Technology, 1998a), and NDF (ANKOM Technology, 1998b; Table 1). Nitrogen-free extract was calculated with the equation NFE = DM – (CP + CF + fat + ash) (Ward Laboratories, Inc.). Bulk density of the wheat midds, DDGS, and complete diets were also determined (Clementson et al., 2010) as well as particle size of the wheat midds and DDGS (ASABE, 2008).

Experiment 1

A total of 180 mixed-sex nursery pigs (initially 11.86 ± 0.02 kg BW and 39 d of age) were used in a 21-d trial to evaluate the effects of increasing dietary wheat midds on nursery pig performance and caloric efficiency. Pigs were allotted to pen by initial BW, and pens were assigned to treatments in a completely randomized design, with 6 pigs per pen and 6 replications per treatment. The 5 treatment diets included 0, 5, 10, 15, or 20% wheat midds (Table 2). Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 to calculate ADG, ADFI, G:F, and caloric efficiency.

Experiment 2

A similar treatment arrangement was used in Exp 1 and 2, but younger and lighter BW pigs were used to evaluate the response in pigs expected to have a lower feed intake. Therefore, a total of 210 mixed-sex nursery pigs (initially 6.85 ± 0.01 kg BW and 26 d of age) were used in a 35-d growth trial to determine the effects of dietary wheat midds on pig performance and caloric efficiency. Pigs were allotted to pens by initial BW, and pens were assigned to treatments with 7 pigs per pen and 6 replications per treatment in a completely randomized design. The 5 treatment diets included 0, 5, 10, 15, or 20% wheat midds (Table 3). Diets were fed in 2 phases, with phase 1 from d 0 to 14 and phase 2 from d 14 to 35. The phase 2 period corresponds approximately to a BW range similar to Exp

Table 1. Chemical analysis of wheat middlings and corn dried distillers grains with solubles (DDGS; as-fed basis)[1,2,3]

	Exp. 1	Exp. 2	Exp. 3		Exp. 4
Item	Wheat middlings	Wheat middlings	Wheat middlings	Corn DDGS	Wheat middlings
DM, %	89.70	91.37	90.45	92.16	89.38
CP, %	16.00 (15.90)	16.10 (15.90)	16.50 (15.90)	29.50(27.20) (27.20)[3]	15.30 (15.90)
ADF, %	9.80	11.00	10.30	10.20	12.30
NDF, %	30.60	33.70	32.40	29.50	35.30
Crude fiber, %	7.90 (7.00)	8.50 (7.00)	8.30 (7.00)	7.10 (7.30)	8.20 (7.00)
NFE, %	72.10	57.00	67.60	40.10	56.10
Ca, %	0.20 (0.12)	0.15 (0.12)	0.10 (0.12)	0.07 (0.03)	0.33 (0.12)
P, %	1.18 (0.93)	1.12 (0.93)	1.07 (0.93)	0.88 (0.71)	1.15 (0.93)
Fat, %	–[4]	3.90 (4.20)	4.50(4.20)	9.50	3.70 (4.20)
Ash, %	–	5.50	5.14	4.81	6.08
Starch, %	–	19.70	18.90	5.90	21.50
Particle size, µ	715(2.10)[5]	532(2.12)	485(1.88)	686(1.94)	574(2.06)
Bulk density, g/L	328	333	344	561	354

[1]Values in parentheses indicate those used in diet formulation.

[2]Values in parentheses are taken from NRC (1998).

[3]Values in parentheses for corn DDGS are taken from Stein (2007).

[4]Values not listed were not available.

[5]Standard deviation for particle size is listed in parentheses.

1. Pig weight and feed disappearance were measured on d 0, 7, 14, 21, 28, and 35 to calculate ADG, ADFI, and G:F.

Experiment 3

A total of 180 mixed-sex nursery pigs (initially 12.18 ± 0.4 kg BW and 39 d of age) were used in a 21-d growth trial to determine the interactive effects of wheat midds and DDGS on pig performance and caloric efficiency. Pigs were allotted to pens by initial BW, so pen initial average BW was similar among pens; pens were then assigned to treatments with 6 pigs per pen and 5 replications per treatment in a completely randomized design. All pigs were fed a common diet before allocation to treatments. The 6 treatment diets were arranged in a 2 × 3 factorial with main effects of wheat midds (0, 10, and 20%) with or without 20% DDGS (Table 4). Pig weight and feed disappearance were measured on d 0, 7, 14, and 21 to calculate ADG, ADFI, and G:F.

Experiment 4

A total of 210 mixed-sex nursery pigs (initially 6.87 kg BW and 26 d of age) were used in a 29-d growth trial to determine the effects of formulating diets on an NE basis on pig performance and caloric efficiency. Pigs were allotted to pens by initial BW, and pens were assigned to treatments with 7 pigs per pen and 6 replications per treatment in a completely randomized design. The 5 corn–soybean meal–based diets were 1) corn–soybean meal diet (positive control), 2) 10% added wheat midds, 3) 20% added wheat midds, 4) treatment 2 with 1.4% added soybean oil, and 5) treatment 3 with 2.8% added soybean oil. Treatment diets 4 and 5 were balanced on an NE basis equal to that of the positive control (Table 5). Thus, this treatment arrangement resulted in a positive control plus a 2 × 2 factorial treatment arrangement with the main effects of the factorial arrangement as balancing for dietary NE content to that of the positive control (no or yes) and wheat midds level (10 or 20%). Feed ingredients were assigned an NE (Sauvant et al., 2004) value for the growing pig, and they were fed in 2 phases, from d 0 to 12 and from d 12 to 29. Pig weight and feed disappearance were measured on d 0, 7, 12, 26, and 29 to calculate ADG, ADFI, and G:F.

Statistical Analysis

For all 4 experiments, data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC), with pen as the experimental unit. All treatment means were analyzed using the LSMEANS statement and preplanned CONTRAST statements in SAS. The preplanned contrasts in Exp. 1 and 2 included the linear and quadratic effects of increasing dietary wheat midds. In Exp. 3, the preplanned contrasts were wheat midds dose (linear and quadratic) × DDGS interactive effect, wheat midds dose main effect (linear and quadratic) of increasing dietary wheat midds regardless of DDGS inclusion and DDGS main effect. In Exp. 4, balanced NE × wheat midds level was evaluated as the interaction between treatments 2 through 4 excluding the positive control (treatment 1). If the interaction was significant, the effect of quadratic

Table 2. Diet composition, Exp. 1 (as-fed basis)[1]

	Wheat middlings, %				
Item	0	5	10	15	20
Ingredient, %					
Corn	63.75	59.95	56.25	52.45	48.7
Soybean meal (46.5% CP)	32.80	31.55	30.35	29.10	27.85
Wheat middlings	–	5.00	10.00	15.00	20.00
Monocalcium phosphate (21% P)	1.050	1.000	0.900	0.825	0.750
Limestone	0.950	0.975	1.025	1.075	1.100
Salt	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.33	0.35	0.37	0.39	0.41
DL-Met	0.135	0.135	0.135	0.135	0.135
L-Thr	0.125	0.135	0.140	0.145	0.155
Phytase[4]	0.125	0.125	0.125	0.125	0.125
Calculated analysis					
Standardized ileal digestible (SID) AA, %					
Lys	1.28	1.28	1.28	1.28	1.28
Ile:Lys	61	61	60	59	59
Met and Cys:Lys	58	58	58	58	58
Thr:Lys	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	68	67	67	67
Total lysine, %	1.42	1.41	1.41	1.41	1.40
ME,[5] kcal/kg	3,310	3,290	3,273	3,255	3,238
NE,[6] kcal/kg	2,362	2,331	2,300	2,269	2,238
SID Lys:ME, g/Mcal	3.86	3.88	3.90	3.93	3.95
Available P,[5] %	0.42	0.42	0.42	0.42	0.42
Analyzed values					
CP, %	20.90	20.30	21.60	19.70	21.00
Crude fiber, %	2.40	2.40	3.00	3.00	3.20
NDF, %	3.20	3.20	3.60	3.70	4.10
ADF, %	8.10	8.00	9.40	9.00	11.60
Ca, %	0.75	0.85	0.86	0.90	0.87
P, %	0.64	0.64	0.65	0.65	0.66

[1]Treatment diets fed for 21 d.

[2]Provided per kilogram of diet: 11,023 IU vitamin A, 1,378 IU vitamin D_3, 44 IU vitamin E, 4 mg vitamin K, 8 mg riboflavin, 28 mg pantothenic acid, 50 mg niacin, and 0.04 mg vitamin B_{12}.

[3]Provided per kilogram of diet: 40 mg Mn from manganese oxide, 17 mg Fe from iron sulfate, 17 mg Zn from zinc sulfate, 2 mg Cu from copper sulfate, 0.30 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units/kg, with a release of 0.12% available P.

[5]NRC, 1998.

[6]Sauvant et al., 2004.

and linear effects of increasing wheat midds level (0, 10, or 20%) within the main effect of balancing were evaluated. If the interaction was not significant, the effect of quadratic and linear effects of increasing dietary wheat midds level (0, 10, or 20%) regardless of NE balancing were evaluated. Main effect of balancing on NE (treatments 2 and 3 vs. treatments 4 and 5) and wheat midds level (treatments 2 and 4 vs. 3 and 5) were also evaluated. In all 4 experiments, least square means were calculated for each independent variable, and results were considered significant at $P < 0.05$ and trends at $P < 0.10$.

RESULTS

Chemical Analysis

Analysis of DDGS and wheat midds verified nutrient values as similar to those used in diet formulation; the minor differences were not expected to influence the results of the experiments. Nutrient analysis of the treatment diets showed that most nutrients levels were similar to formulated values. The only exceptions were CF, Ca, and P, which averaged slightly higher than formulated values.

Analysis of diets revealed that as dietary wheat midds or DDGS increased in the diet, ADF, NDF, and fat increased as expected. Also, as dietary wheat midds or DDGS increased, bulk density decreased.

Experiment 1

Overall (d 0 to 21), as dietary wheat midds increased, ADG and ADFI decreased (linear; $P < 0.05$) in pigs fed increasing wheat midds (Table 6). There was no difference in G:F as wheat midds increased. Caloric efficiency also decreased ($P < 0.05$) on an ME and NE basis as the level of dietary wheat midds increased.

Experiment 2

During phase 1 (d 0 to 14), increasing wheat midds had no effect on performance (Table 7). However, during phase 2 (d 14 to 35), pigs fed increasing wheat midds had decreased (linear; $P < 0.05$) ADG and G:F compared to pigs fed the control diet. Overall (d 0 to 35), as dietary wheat midds increased, G:F decreased (quadratic; $P < 0.013$). For caloric efficiency, the response was quadratic ($P < 0.05$) on an ME and NE basis as the level of wheat midds increased in the diet.

Experiment 3

Overall (d 0 to 21), no wheat midds × DDGS interactions ($P > 0.12$) were observed (Table 8). Increasing dietary wheat midds decreased (linear; $P < 0.05$) ADG, final BW, and G:F, with no effect on ADFI. Adding 20% DDGS to the diet did not influence performance ($P > 0.59$). Caloric efficiencies did not differ when calculated on an ME or NE basis.

Experiment 4

During phase 1 (d 0 to 12), a balanced NE × wheat midds level interaction ($P = 0.009$) was observed for

Table 3. Diet composition phase 1 and 2, Exp. 2 (as-fed basis)[1]

	Phase 1					Phase 2				
	Wheat middlings,%:									
Item	0	10	20	10	20	0	10	20	10	20
Ingredient, %										
Corn	54.77	51.01	47.25	43.49	39.73	63.74	59.97	56.22	52.45	48.71
Soybean meal (46.5% CP)	29.32	28.09	26.86	25.63	24.40	32.79	31.56	30.33	29.10	27.87
Wheat middlings	–	5.00	10.00	15.00	20.00	–	5.00	10.00	15.00	20.00
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	–	–	–	–	–
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	–	–	–	–	–
Monocalcium phosphate (21% P)	0.650	0.575	0.500	0.425	0.350	1.050	1.000	0.900	0.825	0.750
Limestone	0.875	0.913	0.950	0.988	1.025	0.950	0.975	1.025	1.075	1.100
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.25	0.27	0.29	0.31	0.33	0.33	0.35	0.37	0.39	0.41
DL-Met	0.130	0.130	0.130	0.130	0.130	0.135	0.135	0.135	0.135	0.135
L-Thr	0.125	0.138	0.140	0.148	0.155	0.125	0.135	0.140	0.145	0.155
Phytase[4]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Calculated analysis										
Standardized ileal digestible (SID) AA, %										
Lys	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Ile:Lys	62	62	61	60	60	61	61	60	59	59
Met and Cys:Lys	58	58	58	58	58	58	58	58	58	58
Thr:Lys	65	65	65	65	65	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	68	68	68	67	68	68	67	67	67
Total Lys, %	1.46	1.46	1.45	1.45	1.45	1.42	1.41	1.41	1.41	1.40
ME,[5] kcal/kg	3,302	3,284	3,266	3,249	3,231	3,310	3,290	3,273	3,255	3,238
NE,[6] kcal/kg	2,401	2,370	2,340	2,309	2,278	2,362	2,331	2,300	2,269	2,238
SID Lys:ME, g/Mcal	3.99	4.01	4.04	4.06	4.08	3.86	3.88	3.90	3.93	3.95
Available P,[5] %	0.48	0.48	0.48	0.48	0.48	0.42	0.42	0.42	0.42	0.42
Analyzed values										
CP, %	22.20	21.30	22.00	24.00	20.90	21.40	20.90	21.10	21.30	21.10
Crude fiber, %	1.80	2.20	2.60	3.00	2.90	2.40	2.70	3.40	3.30	3.70
NDF, %	3.10	3.20	4.10	4.70	4.10	3.30	4.10	5.00	5.10	5.60
ADF, %	6.70	8.00	9.10	11.40	11.20	7.60	9.10	14.10	11.90	14.00
Ca, %	1.12	1.17	1.18	1.10	1.11	0.77	0.81	0.92	1.17	0.79
P, %	0.67	0.63	0.73	0.71	0.71	0.62	0.63	0.71	0.74	0.72

[1]Phase 1 diets were feed from d 0 to 14; phase 2 diets were fed from d 14 to 35.

[2]Provided per kilogram of diet: 11,023 IU vitamin A, 1,378 IU vitamin D_3, 44 IU vitamin E, 4 mg vitamin K, 8 mg riboflavin, 28 mg pantothenic acid, 50 mg niacin, and 0.04 mg vitamin B_{12}.

[3]Provided per kilogram of diet: 4 mg Mn from manganese oxide, 17 mg Fe from iron sulfate, 17 mg Zn from zinc sulfate, 2 mg Cu from copper sulfate, 0.30 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units/kg, with a release of 0.12% available P.

[5]NRC, 1998.

[6]Sauvant et al., 2004.

ADFI (Table 9). As more wheat midds were added to the diet and not balanced for NE, pigs had increased ADFI (linear; $P = 0.0486$). Conversely, ADFI increased (0 to 10%) and then decreased (10 to 20%) in diets balanced for NE (quadratic; $P = 0.025$). During phase 2 (d 12 to 29), increasing dietary wheat midds decreased (quadratic; $P = 0.030$) G:F, but ADG and ADFI were not significantly influenced. Overall (d 0 to 29), no balanced NE × wheat midds level interactions were observed. Pigs fed increasing dietary wheat midds had a tendency for poorer (linear; $P < 0.10$) G:F and caloric efficiency when expressed on an ME basis. Poorer ($P < 0.05$) G:F and caloric efficiency on an ME basis were also found as wheat midds level increased in the diets regardless of balancing for NE or not, but no differences were observed for energetic efficiency on an NE basis.

Table 4. Diet composition, Exp. 3 (as-fed basis)[1]

	Corn DDGS,[2] %					
	0			20		
	Wheat middlings, %					
Item	0	10	20	0	10	20
Ingredient, %						
Corn	63.74	56.22	48.71	47.57	40.05	32.54
Soybean meal (46.5% CP)	32.79	30.33	27.87	29.27	26.81	24.34
Corn DDGS	–	–	–	20.00	20.00	20.00
Wheat middlings	–	10.00	20.00	–	10.00	20.00
Monocalcium phosphate (21% P)	1.05	0.90	0.75	0.60	0.45	0.30
Limestone	0.95	1.03	1.10	1.20	1.28	1.35
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.33	0.37	0.41	0.37	0.41	0.45
DL-Met	0.135	0.135	0.135	0.045	0.045	0.045
L-Thr	0.125	0.140	0.155	0.070	0.085	0.100
Phytase[4]	0.125	0.125	0.125	0.125	0.125	0.125
Calculated analysis						
Standardized ileal digestible (SID) AA, %						
Lys	1.28	1.28	1.28	1.28	1.28	1.28
Ile:Lys	61	60	59	65	64	62
Met and Cys:Lys	58	58	58	58	58	58
Thr:Lys	63	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	67	67	74	73	73
Total Lys, %	1.42	1.41	1.40	1.45	1.45	1.44
ME,[5] kcal/kg	3,310	3,273	3,238	3,317	3,279	3,244
NE,[6] kcal/kg	2,362	2,300	2,238	2,388	2,326	2,265
SID Lys:ME, g/Mcal	3.86	3.90	3.95	3.85	3.90	3.94
Available P,[5] %	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed values						
CP, %	22.30	21.60	21.20	23.90	23.80	22.30
Crude fiber, %	2.40	2.90	3.30	3.10	3.80	4.30
NDF, %	2.30	3.10	3.70	4.40	5.50	5.50
ADF, %	9.20	12.10	14.90	11.40	14.60	14.70
Ca, %	0.85	0.91	0.83	0.80	0.87	0.73
P, %	0.63	0.66	0.68	0.62	0.68	0.68

[1]Treatment diets fed for 21 d.

[2]DDGS = dried distillers grains with solubles.

[3]Provided per kilogram of diet: 11,023 IU vitamin A, 1,378 IU vitamin D_3, 44 IU vitamin E, 4 mg vitamin K, 8 mg riboflavin, 28 mg pantothenic acid, 50 mg niacin, and 0.04 mg vitamin B_{12}.

[4]Provided per kilogram of diet: 4 mg Mn from manganese oxide, 17 mg Fe from iron sulfate, 17 mg Zn from zinc sulfate, 2 mg Cu from copper sulfate, 0.30 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units/kg, with a release of 0.12% available P.

[6]NRC, 1998.

[7]Sauvant et al., 2004.

DISCUSSION

The majority of published research with wheat midds or wheat shorts has been conducted with finishing pigs. Young (1980) conducted 2 studies that indicated growing pigs fed increasing levels of wheat shorts from 18 to 44 kg had decreased ADG, but only if 64.4% wheat shorts were included in the diet, whereas finishing pigs fed from 21 kg to slaughter had decreased ADG after 32.2% wheat shorts or more were used. In both studies, G:F decreased as dietary wheat shorts were added to the diet. Dietary Lys and energy decreased as wheat shorts were added to the diet. However, all Lys levels were at or above recommended concentrations (NRC, 1979), which subsequently also met requirements from NRC (1998). Feoli et al. (2006) conducted a study feeding increasing levels of wheat midds to finishing pigs from 65 kg BW to slaughter. Pigs were fed wheat midds at inclusion rates of 0, 15, and 30% with or without the use of a commercial xylanase enzyme. Diets were not isocaloric but were isonitrogenous, such that as wheat midds increased in the diet, energy content decreased but AA levels remained constant. Pigs fed increasing wheat midds from 0 to 30% had decreased ADG, G:F, and HCW. The enzyme had no effect, but the increasing wheat midds decreased apparent digestibility of DM, N, and GE. Asmus et al. (2012) fed wheat midds to finishing pigs from 38 kg to slaughter at levels of 0 or 19% with isocaloric and isonitrogenous diets. Pigs fed diets containing wheat midds had decreased ADG, G:F, final BW, and HCW. Erickson et al. (1985) fed pigs 20, 40, or 60% wheat midds from 11 or 21 kg BW to slaughter. They observed that pigs fed increasing wheat midds had decreased ADG and G:F, mainly due to decreases that occurred if more than 20% wheat midds were included in the diets. In this study, diets were isonitrogenous and isocaloric such that Lys and energy levels were held constant as wheat midds increased in the diet.

In the present studies with nursery pigs, a common observation was that despite linear decreases in ADG and G:F, the greatest detriment was observed with wheat midds greater than 10 or 15% of the diet. This response occurred as a result of decreased calculated dietary energy content. Shaw et al. (2002) observed that wheat midds inclusion levels of up to 30% had no effect on ADG, ADFI, or G:F for pigs fed from 8 to 28 kg BW. However, Erickson et al. (1985) reported that increasing dietary wheat midds as an equal replacement for corn at levels of 0, 10, 20, or 30% decreased ADG and G:F and increased ADFI when fed to pigs with an initial BW of 11 kg for 4 wk.

The variability in response to wheat midds inclusion in diets for nursery pigs may be due to the variability among wheat midds sources. Cromwell et al. (2000) observed that 14 sources of wheat midds had differences in bulk density, DM, CP, Ca, P, Se, and NDF. Cromwell et al. (1992) reported that pigs fed "heavy" wheat midds, classified by a high bulk density, had improved performance compared with those fed identical levels of "light" wheat midds. Light wheat midds have very few starch particles and consist of a larger proportion of bran than "heavy"

Table 5. Diet composition, Exp. 4 (as-fed basis)

	Phase 1					Phase 2				
	Corn DDGS,[2] %									
	0	10	20	10	20	0	10	20	10	20
	Soybean oil, %									
Item	0	0	0	1.40	2.80	0	0	0	1.40	2.80
Ingredient, %										
Corn	54.77	47.25	39.73	45.75	36.72	63.74	56.22	48.71	54.72	45.69
Soybean meal (46.5% CP)	29.32	26.86	24.40	26.97	24.62	32.79	30.33	27.87	30.44	28.09
Wheat middlings	–	10.00	20.00	10.00	20.00	–	10.00	20.00	10.00	20.00
Select menhaden fish meal	3.00	3.00	3.00	3.00	3.00	–	–	–	–	–
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	–	–	–	–	–
Soybean oil	–	–	–	1.40	2.80	–	–	–	1.40	2.80
Monocalcium phosphate (21% P)	0.65	0.50	0.35	0.50	0.35	1.05	0.90	0.75	0.90	0.75
Limestone	0.88	0.95	1.03	0.95	1.03	0.95	1.03	1.10	1.03	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.25	0.29	0.33	0.29	0.33	0.33	0.37	0.41	0.37	0.41
DL-Met	0.130	0.130	0.130	0.130	0.130	0.135	0.135	0.135	0.135	0.135
L-Thr	0.125	0.140	0.155	0.140	0.155	0.125	0.140	0.155	0.140	0.155
Phytase[4]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Calculated analysis										
Standardized ileal digestible (SID) AA, %										
Lys	1.32	1.32	1.32	1.32	1.32	1.28	1.28	1.28	1.28	1.28
Ile:Lys	62	61	60	61	59	61	60	59	60	59
Met and Cys:Lys	58	58	58	58	58	58	58	58	58	58
Thr:Lys	65	65	65	65	65	63	63	63	63	63
Trp:Lys	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Val:Lys	68	68	67	68	67	68	67	67	67	66
Total Lys, %	1.46	1.45	1.45	1.45	1.45	1.42	1.41	1.40	1.41	1.40
ME,[5] kcal/kg	3,302	3,266	3,231	3,335	3,370	3,310	3,273	3,238	3,343	3,376
NE,[6] kcal/kg	2,401	2,340	2,278	2,401	2,401	2,362	2,300	2,238	2,362	2,362
SID Lys:ME, g/Mcal	3.99	4.04	4.08	3.95	3.91	3.86	3.90	3.95	3.82	3.78
Available P,[5] %	0.36	0.36	0.36	0.36	0.36	0.30	0.30	0.30	0.30	0.30
Analyzed values										
CP, %	21.8	22.0	21.2	22.0	21.8	21.5	22.3	21.7	21.6	20.8
Crude fiber, %	2.4	2.5	2.9	2.4	2.8	2.2	2.9	3.4	2.8	3.4
NDF, %	4.1	4.1	4.2	3.7	3.3	2.8	4.4	5.1	4.1	4.9
ADF, %	8.0	8.9	10.0	8.5	9.6	9.0	13.2	13.5	10.0	13.0
Ca, %	1.74	1.27	1.89	1.45	1.23	1.03	1.11	1.36	1.13	0.99
P, %	0.69	0.70	0.82	0.67	0.71	0.63	0.72	0.74	0.71	0.68

[1]Treatment diets fed for 21 d.

[2]DDGS = dried distillers grains with solubles; Provided per kilogram of diet: 11,023 IU vitamin A, 1,378 IU vitamin D_3, 44 IU vitamin E, 4 mg vitamin K, 8 mg riboflavin, 28 mg pantothenic acid, 50 mg niacin, and 0.04 mg vitamin B_{12}.

[3]Provided per kilogram of diet: 4 mg Mn from manganese oxide, 17 mg Fe from iron sulfate, 17 mg Zn from zinc sulfate, 2 mg Cu from copper sulfate, 0.30 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 749.4 phytase units/kg, with a release of 0.12% available P.

[5]NRC, 1998.

[6]Sauvant et al., 2004.

wheat midds. The differences among sources of wheat midds are mainly due to processing techniques used in flour milling as well as the region the wheat was grown; for example, hard red wheat is higher in CP than soft red wheat. All wheat midds used in our experiments are considered "heavy" wheat midds based on bulk density analysis and may have contained more starch than other "light" wheat midds sources. This may explain the similar performance in pigs fed diets containing 10 to 15% wheat midds and those fed the corn–soybean meal control diets.

In Exp. 2 and 4, increasing dietary wheat midds did not affect performance of nursery pigs from 7 to 10 kg.

Table 6. The effects of increasing wheat middlings on nursery pig performance, Exp. 1[1]

	Wheat middlings, %						Probability, $P <$	
Item	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 21								
ADG, g	578	568	565	568	547	9	0.049	0.662
ADFI, g	945	941	903	916	892	13	0.004	0.802
G:F	0.611	0.603	0.626	0.620	0.613	0.007	0.368	0.351
Caloric efficiency, Mcal/kg								
ME	5.43	5.47	5.25	5.26	5.29	0.06	0.023	0.372
NE	3.87	3.88	3.68	3.66	3.66	0.04	0.001	0.357
Wt, kg								
d 0	11.9	11.9	11.8	11.9	11.9	0.2	0.956	0.924
d 21	24.0	23.8	23.7	23.8	23.4	0.3	0.264	0.853

[1]A total of 180 pigs (PIC 327 × 1050, initially 11.86 ± 0.02 kg BW and 39 d of age) were used in a 21-d growth trial with 6 pigs per pen and 6 pens per treatment.

However, greater than 10% wheat midds had negative effects on both ADG and G:F after 10 kg. This result supports data of Weber et al. (2008), indicating that fibrous feed ingredients (DDGS, soybean hulls, and citrus pulp) did not affect performance of pigs from 5 to 15 kg. The decrease in performance for older nursery pigs may have been a result of the increased diet bulk density as well as the increasing NDF content of the diets as wheat midds were increased. Palatability of a new diet may also explain the decreased performance. In Exp. 1 of the present studies, ADFI decreased as wheat midds increased, indicating that feed intake may have been limited by gut fill due to the low bulk density of the wheat midds. The reduction in diet bulk density may have hindered pigs from consuming more total feed to meet their energy requirements but is unclear due to the lack of an ADFI response in Exp.3 and 4. Avelar et al. (2010) reported reductions in ADG, ADFI, and G:F when feeding increasing dietary wheat DDGS to 7- to 17-kg nursery pigs. The decreased performance was attributed to the decreased bulk density of the diets as dietary wheat DDGS increased. Ndou et al. (2012) also observed that diet bulk density was associated with decreased ADFI when pigs were fed diets containing increasing amounts of highly fibrous feedstuffs.

The inclusion of corn DDGS in nursery diets has been shown to have little or no effect on nursery pig performance at levels up to 45% (Senne et al., 1995; Linneen et al., 2006; Weber et al., 2008) or even to slightly improve G:F (Barbosa et al., 2008), but all of these studies were in corn–soybean meal–based diets without other coproducts. In the current studies, no interactions were observed between DDGS and wheat midds

Table 7. The effects of increasing wheat middlings on nursery pig performance, Exp. 2[1]

	Wheat middlings, %						Probability, $P <$	
Item	0	5	10	15	20	SEM	Linear	Quadratic
d 0 to 14								
ADG, g	205	210	213	200	209	14	0.986	0.885
ADFI, g	328	313	316	318	334	15	0.760	0.297
G:F	0.621	0.669	0.666	0.627	0.628	0.023	0.694	0.143
d 14 to 35								
ADG, g	585	585	578	569	543	12	0.020	0.257
ADFI, g	878	862	880	861	860	18	0.548	0.928
G:F	0.666	0.679	0.657	0.662	0.632	0.008	0.003	0.071
d 0 to 35								
ADG, g	433	435	432	422	408	12	0.111	0.391
ADFI, g	658	643	654	644	647	16	0.691	0.812
G:F	0.658	0.677	0.660	0.655	0.631	0.007	0.004	0.013
Caloric efficiency, Mcal/kg								
ME	5.04	4.87	4.97	4.98	5.14	0.06	0.098	0.013
NE	3.61	3.46	3.51	3.48	3.57	0.04	0.615	0.014
BW, kg								
d 0	6.9	6.9	6.9	6.9	6.9	0.6	0.875	0.933
d 14	9.7	9.8	9.8	9.7	9.8	0.2	0.953	0.903
d 35	22.0	22.1	22.0	21.6	21.3	0.4	0.146	0.492

[1]A total of 210 pigs (PIC 327 × 1050, initially 6.85 ± .01 kg BW and 26 d of age) were used in a 35-d growth trial with 7 pigs per pen and 6 pens per treatment.

Table 8. The effects of wheat middlings and dried distillers grains with solubles (DDGS) on nursery pig growth performance, Exp. 3[1]

Item	DDGS, %		SEM	Wheat middlings, %			SEM	Probability,[2] $P <$	
								Wheat middlings	
	0	20		0	10	20		Linear	Quadratic
d 0 to 21									
ADG, g	573	572	9	587	571	559	11	0.015	0.984
ADFI, g	933	944	15	938	938	940	19	0.5651	0.784
G:F	0.614	0.607	0.006	0.627	0.609	0.566	0.008888	0.011	0.822
Caloric efficiency, Mcal/kg									
ME	5.35	5.42	0.06	5.29	5.39	5.47	0.08	0.145	0.808
NE	3.76	3.84	0.04	3.80	3.81	3.80	0.05	0.843	0.774
BW, kg									
d 0	12.1	12.3	0.2	12.1	12.1	12.3	0.2	0.590	0.785
d 21	24.1	24.3	0.3	24.5	24.2	24.1	0.4	0.021	0.984

[1]A total of 180 pigs (PIC 327 × 1050, initially 12.18 ± 0.4 kg BW and 39 d of age) were used in a 21-d growth trial with 6 pigs per pen and 5 pens per treatment.

[2]Wheat middlings dose (linear and quadratic) × DDGS or DDGS main effects, $P > 0.316$.

for nursery pig performance despite further decreased diet bulk density and increased dietary fiber levels when both ingredients were included in the diets. Results of research with finishing pigs by Asmus et al. (2012) and Salyer et al. (2012) also indicated that there were no interactions between wheat midds and DDGS, although wheat midds negatively affected performance.

The first 3 trials in the present study were not isocaloric, but the final experiment evaluated equal NE formulation using added soybean oil to balance the NE levels

Table 9. The effects of increasing wheat middlings and net energy formulation on nursery pig performance, Exp. 4[1]

Item	Treatment					SEM	Probability,[2,3] $P <$			
	1	2	3	4	5					
	Wheat middlings, %									
	0	10	20	10	20					
	Soybean oil, %						Balanced NE × wheat middlings level	Wheat middlings[4]		Wheat middlings level[5]
	0	0	0	1.4	2.8			Linear	Quadratic	
d 0 to 12										
ADG, g	252	258	261	275	258	9	0.326	0.562	0.271	0.495
ADFI, g[6]	424	428	466	465	423	14	0.009	0.252	0.362	0.881
G:F	0.597	0.602	0.563	0.590	0.609	0.024	0.176	0.672	0.806	0.626
d 12 to 29										
ADG, g	576	569	540	581	569	11	0.462	0.147	0.369	0.089
ADFI, g	878	863	861	874	899	16	0.436	0.910	0.515	0.498
G:F	0.656	0.660	0.628	0.665	0.634	0.009	0.958	0.027	0.030	0.001
d 0 to 29										
ADG, g	442	440	425	454	440	9	0.945	0.408	0.254	0.120
ADFI, g	690	683	698	705	701	14	0.537	0.601	0.959	0.712
G:F	0.641	0.645	0.610	0.644	0.627	0.013	0.349	0.069	0.106	0.011
Caloric efficiency, Mcal/kg										
ME	5.17	5.09	5.33	5.20	5.40	0.08	0.821	0.065	0.116	0.012
NE	3.74	3.62	3.74	3.73	3.81	0.06	0.769	0.640	0.165	0.115
BW, kg										
d 0	6.9	6.9	6.9	6.9	6.9	0.1	0.980	0.980	0.957	0.948
d 12	9.9	10.0	10.0	10.2	10.0	0.2	0.461	0.679	0.411	0.603
d 29	19.7	19.6	19.2	20.0	19.7	0.3	0.826	0.558	0.362	0.229

[1]A total of 210 pigs (PIC 327 × 1050, initially 6.87 kg BW and 26 d of age) were used in a 29-d growth trial with 7 pigs per pen and 6 pens per treatment.

[2]Balanced NE × wheat middlings level was evaluated as the interaction between treatments 2 through 4.

[3]Main effect of balancing on NE (treatments 2 and 3 vs. treatments 4 and 5; $P > 0.12$).

[4]Combines treatments 2 and 4 and 3 and 5 to create a 0, 10, and 20% wheat middlings level quadratic or linear contrast.

[5]Compares treatments 2 and 4 vs. 3 and 5.

[6]Wheat middlings level within without balancing for NE (linear; $P = 0.0486$) and within balancing for NE (quadratic; $P = 0.025$).

when diets contained 10 or 20% wheat midds. In this case, performance was restored and no negative effects of increasing wheat midds in the diet were observed for growth rate. This result supports work in finishing pigs by Shaw et al. (2002) and Salyer et al. (2012), which indicated that the use of added fat to balance the dietary energy concentration when wheat midds were added to diets may mitigate the negative effects of wheat midds. In practical formulation, the added cost of fat must be considered in the overall economic analysis of ingredient selection and production goals.

When formulating diets containing high levels of byproducts such as wheat midds and DDGS, assigning accurate energy concentrations to these byproducts is essential to establish accurate feeding values. Caloric efficiency can be calculated to determine if the assigned ingredient energy concentration is accurate. This approach can be applied to all energy systems used in diet formulation to determine if the energy value assigned to a particular ingredient is accurate. If the assigned energy value is correct, regardless of the test ingredient inclusion level, a similar caloric efficiency will be calculated. If significant differences in caloric efficiencies of diets containing increasing levels of the test ingredient are observed, the energy level for the ingredient was likely underestimated or overestimated in formulation. However, the energy level of an ingredient may change based on the level used in the diets, especially in higher fiber ingredients. Just (1982) reported that for every 1% increase in the CF content of a diet, the digestible ME decreased by 1%, which indicated that an ingredient's actual energy value may change as the level of the ingredient in the diet changes. Stewart et al. (2013) estimated the NE value of wheat midds using complete body composition of growing (25.4 kg BW) and finishing (84.8 kg BW) pigs fed 0 or 30% wheat midds. They observed that the NE of the diet containing wheat midds was lower than the basal diet for growing pigs and tended to be lower in the finishing phase. The energy concentration of wheat midds was also numerically greater when fed to finishing pigs (1,015 vs. 959 kcal/kg) compared with growing pigs. This result indicated that current NE values (1,560 kcal/kg; NRC, 1998; 1,850 kcal/kg; Sauvant et al., 2004) may be overestimating the caloric content of wheat midds, but because only 1 level of wheat midds inclusion was tested that was much greater than any levels used in the present experiments, it might suggest that as wheat midds are added to the diet at high levels, the digestibility of other ingredients may be affected and thus decrease the calculated NE concentration of wheat midds.

In conclusion, nursery pigs fed diets with increasing wheat midds had decreased performance when diets were isocaloric, but the decrease in performance occurred only when wheat midds were fed at levels over 10 to 15% of the diet. The INRA (Sauvant et al., 2004) NE value of wheat midds appears to be a more accurate energy value than the ME value from the NRC (1998) based on caloric efficiencies, but more work needs to be conducted to fully understand the energetic value based on inclusion rate and the age of the pig.

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